Impact Assessment of Climate Change and Sea Level Rise on Monsoon Flooding

June 2009

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Climate Change Cell
Department of Environment

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Foreword

The impacts of global warming and climate change are worldwide. For Bangladesh they are most critical because of its geographical location, high population density, high levels of poverty, and the reliance of many livelihoods on climate-sensitive sectors, such as agriculture, fisheries.

To address current impacts and manage future risks of climate change and variability towards development of a climate resilient Bangladesh, the government has established the Climate Change Cell (CCC) in the Department of Environment (DoE) under the Comprehensive Disaster Management Programme (CDMP). Climate change research, covering modeling and adaptation is one of the major activities of the Cell.

CCC in association with its Technical Advisory Group (TAG) and other stakeholders identified a set of research activities related to climate change in Bangladesh through a number of consultations. The activities have been prioritized and a number of projects have been commissioned in last few years.

Bangladesh is prone to various natural hazards and calamities including seasonal flood, flash flood, storm, cyclone etc. It is predicted that impacts of climate change will increase the intensity, frequency and magnitude of hazards leading to more frequent disasters. Natural disaster can not be prevented or controlled but advance knowledge of its occurrence is very much important for national disaster planners. However, to understand impacts of climate change on occurrences of future disaster events and to treat risks originating from such events modeling exercises are being practiced worldwide to predict impacts of climate change. In Bangladesh, Climate modeling has been introduced very recently. Cell undertook several initiatives to provide model output of the impacts of climate change to the relevant institutions and stakeholder groups in Bangladesh.

Flood, in Bangladesh is an annual recurring event and the country very often experiences devastating flood during monsoon that causes damage to crops and properties as well as human lives. It is expected that due to increase of precipitation and sea level rise caused by climate change the situation will be worse.

The study indicated that severe flood may occur more frequently in future in Bangladesh. Model results also show that inundated area is likely to increase while the duration of flood is predicted to be prolonged by a significant number of days. It is also evident from the model that moderate flood with increased precipitation would cause in less availability of cultivable land area.

It is expected that the research will create a strong link between modeling community and other stakeholders to share research results and needs. This study was conducted in some representative locations. Considering growing importance of impact of climate change such study needs to be undertaken for entire Bangladesh. That will facilitate policy makers and planners to formulate viable adaptation policies, strategies and action plan.

Zafar Ahmed Khan, PhD
Director General
Department of Environment

Acronyms and Abbreviations

AOGCM	Atmosphere-Ocean General Circulation Model
AR4	Fourth Assessment Report
BCAS	Bangladesh Centre for Advanced Studies
BWDB	Bangladesh Water Development Board
BIWTA	Bangladesh Inland Water Transport Authority
CCC	Climate Change Cell
CDMP	Comprehensive Disaster Management Programme
CEARS	Centre for Environmental Applications of Remote Sensing
DJF	December January February
DoE	Department of Environment
DHI	Danish Hydraulic Institute
EHRM	Eastern Hilly Region Model
FFWC	Flood Forecasting and Warning Center
GBM	Ganges, Brahmmaputra and Meghna
GM	General Model
IPCC	Intergovernmental Panel on Climate Change
ICZM	Integrated Coastal Zone Management
IWM	Institute of Water Modelling
JJA	June July August
LLGHGs	Long-Lived Green House Gases
LGED	Local Government Engineering Department
MAM	March April May
MPO	Master Plan Organisation
MSL	Mean Sea Level
NWRM	North West Region Model
NCRM	North Central Region Model
NERM	North East Region Model
NAPA	National Adaptation Program of Action
OECD	Organization for Economic Co-operation and Development
SMRC	SAARC Meteorological Research Centre
SRES	Special Report on Emission Scenarios
SLR	Sea Level Rise
SERM	South East Region Model
SON	September October November
SWRM	South West Region Model
TAR	Third Assessment Report
WPGSP	Working Party on Global and Structural Policies
WARPO	Water Resources Planning Organization

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Executive Summary

E.1 INTRODUCTION

Bangladesh is extremely vulnerable to climate change because of its geophysical settings. It is a low-lying flat country with big inland water bodies, including some of the biggest rivers in the world. Flooding is an annual recurring event during monsoon and 80% of annual rainfall occurs in monsoon. Bangladesh is a flood prone country and very often experiences devastating flood during monsoon that causes damage to crops and properties. In normal years, about one fifth of the country is flooded. The total drainage area of Ganges-Brahmaputra-Meghna (GBM) basin is 1.75 million sq.km and the average annual water flow is 1350 billion cubic meters, which is drained through Bangladesh but the GBM basin area within Bangladesh is only about 7-10% of the total area. If rainfall increases due to climate change in the GBM basin that will create huge water flow through the rivers of Bangladesh. Eventually the monsoon flood will be more devastating due to increase of precipitation and sea level rise that may cause more damage to crops and properties if adaptation measures are not taken.

This study assessed the impacts of climate change and sea level rise on monsoon flood and land type for seven districts in different hydrological regions of Bangladesh since impact on land type determines the change on agricultural yield as it is associated with cropping pattern.

E.2 CLIMATE CHANGE SCENARIO

Sea Level Rise

In the 4th IPCC report the sea level rise for different emission scenarios has not been given but a global sea level rise pattern for the IS92a[1] scenario has been given and is shown in the Figure E.1. From this prediction it has been found that the sea level will rise up to 59 cm in 2100.

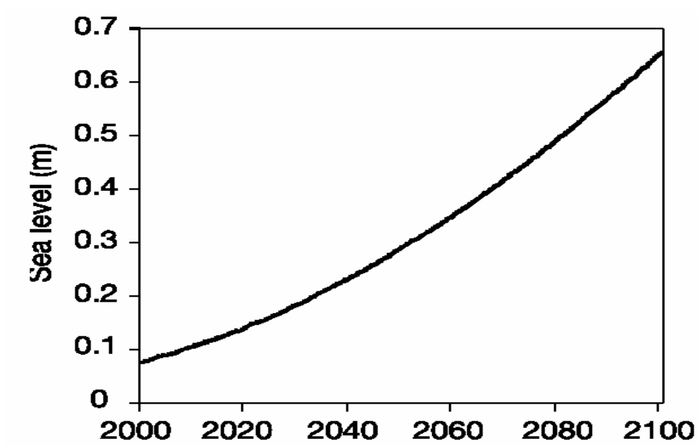

Figure E.1: Prediction of global sea level rise according to IS92a scenario (AR4, 2007)

Note[1]: IS92a scenario is used as a reference from which to develop other scenarios.

Sea level rise for different years according to IS92a scenario has been calculated from the Figure 4.1 and has been shown in Table E.1.

Table E.1: Predicted sea level rise for the next 100 years

Year	Sea Level Rise (cm) above year 2000 level
2020	8
2030	12
2040	17
2050	23
2060	29
2070	36
2080	43
2090	51
2100	59

Precipitation:

The future precipitation pattern of Bangladesh can not be obtained directly from the 4th IPCC report. However, future precipitation condition of South Asia can be calculated from the report which is presented in the Table E.2.

Table E.2: Predicted precipitation for the next 100 years

Sub-regions	Season	2010 - 2039		2040 - 2069		2070 - 2099	
		A1Fl[2]	B1[2]	A1Fl	B1	A1Fl	B1
South Asia	DJF[3]	-3	4	0	0	-16	-6
	MAM[3]	7	8	26	24	31	20
	JJA[3]	5	7	13	11	26	15
	SON[3]	1	3	8	6	26	10

The precipitation predicted under A1Fl is considered for the present study i.e. 13% increase is taken for hydrological and flood modelling.

E.3 BASELINE CONDITION

In the present study flood events of 2005 and 2004 are considered to establish baseline/reference condition since statistical analysis shows these floods are average and moderate flood event in the Ganges and Brahmaputra basins. The inundation during monsoon for baseline condition has been assessed through application of calibrated and validated regional flood models for the hydrological year 2005 and 2004. Inundation has been categorized in depth classes as: F0(0-30cm), F1(30-90 cm), F2(90-180 cm), F3(180-360 cm) and F4(>360cm). District wise description of baseline condition has been presented in the Table E.3.

Note[2]: A1 Scenario – based on homogeneous world of very rapid economic growth, high global population that peaks in mid-century and the rapid introduction of new and more efficient technologies. It represents a convergent world with a substantial reduction in regional per capita income. Based on emission it is divided into three categories such as A1Fl, A1T and A1B.

A1Fl – Based on fossil fuel intensive – represent very high emission.

B1 Scenario: based on convergent world with the same global populations as in A1 but with rapid change in economic structures and the introduction of clean and resource-efficient technologies. Special emphasis is given on global solution to economic, social and environmental sustainability including improved equity. It represents very low emission.

Note[3]: DJF: December, January & February; MAM: March. April & May; JJA: June, July & August; SON: September, October &November.

Table E.3: Inundated area in different depth categories in an average flood condition

Districts	Area (km²)		Land Type (km²)				
			F0	F1	F2	F3	F4
Faridpur	2072.72	Inundation at 2005	32.04	156.60	289.80	186.57	10.35
		Area in %	1.55	7.56	13.98	9.00	0.50
Sirajganj	2497.92	Inundation at 2005	58.23	401.49	699.21	423.90	12.24
		Area in %	2.33	16.07	27.99	16.97	0.49
Sunamganj	3669.58	Inundation at 2005	882.17	371.43	699.48	1178.10	472.95
		Area in %	24.04	10.12	19.06	32.10	12.89
Satkhira	3858.33	Inundation at 2005	35.91	121.50	392.31	1844.37	0.09
		Area in %	0.93	3.15	10.17	47.80	0.00
Barisal	2790.51	Inundation at 2005	117.63	975.33	749.43	78.12	0.00
		Area in %	4.22	34.95	26.86	2.80	0.00
Gaibandha	2179.27	Inundation at 2005	74.43	414.81	479.79	104.04	0.36
		Area in %	3.42	19.03	22.02	4.77	0.02
Pabna	2371.5	Inundation at 2005	61.56	219.96	487.08	553.68	126.18
		Area in %	2.60	9.28	20.54	23.35	5.32

E.4 CHANGE OF FREQUENCY OF CHARACTERISTICS FLOOD

Efforts have been made to examine the increase of occurrence of characteristic flood over the historical years. Time series water flow of Jamuna river at Bahadurabad is available from 1956 to 2007. All the available data have been divided into three parts 1956-73, 1974-1990 and 1991-2007 to carry out statistical analysis to investigate the increase of number occurrence of a specific flood event. Frequency analysis has been done for each part. From the analysis of first part it has been seen that a flood flow of 76,137 m^3/s has a return period of 25 year which means it may occur 4 times in the next 100 years. In the analysis of second part the same flood flow shows return period of 5 year which means that it may occur 20 times in the next 100 years. From the frequency analysis of third part it has been found that the return period for the above water flow is 3.5 year which means that it may occur 28 times in the next 100 years. This analysis shows number of occurrence of a particular flood has increased over the years, which is shown in the Figure 3.1. This indicates that severe flood may come more frequently in future. However, this needs more analysis of flow and rainfall.

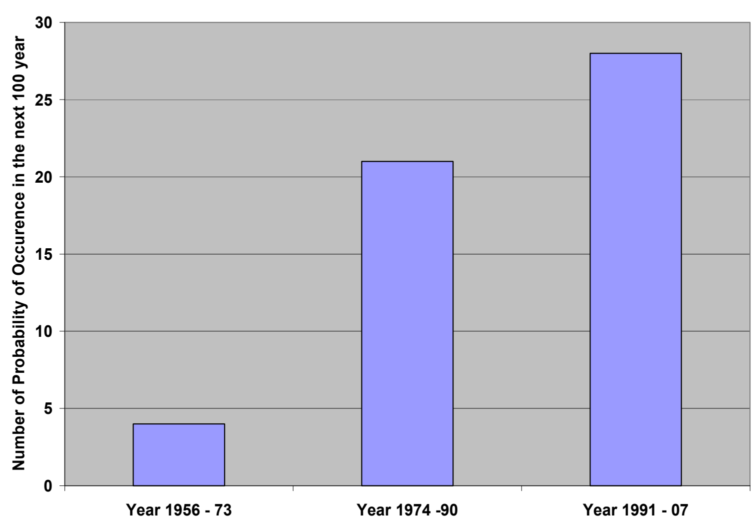

Figure E.2: Increase in number of occurrence of characteristic flood over the historical years at Bahadurabad.

E.5 IMPACT OF CLIMATE CHANGE ON MONSOON FLOOD

Bangladesh will experience more floods, more droughts, drainage congestion, salinity intrusion and cyclones with higher intensities due to climate change. In order to devise adaptation options to make Bangladesh climate resilient, it is important to know, the extent, intensity and magnitude of impacts of climate change and its implication on livelihood and food security.

Inflow in the major rivers has been generated using calibrated GBM basin model increasing the precipitation by 13% over the GBM basin and 17 cm sea level rise is considered in accordance with the IPCC prediction to establish flood flow, flood level and its duration during monsoon in 2040. Impacts on flooding and land type have been assessed comparing the inundated area of different depths in 2040 with that of 2004 and 2005. The impact has been ascertained during peak flood considering one day duration and depth equal to and greater than 30 cm. Model results show that inundated area has increased by 12 to 16 per cent in the Ganges and Jamuna basin for an average or normal flood event due to climate change as shown in Table E.4.

Table E.4 Impact of climate change on flood inundated area

Upazilla	Area (Km^2)	Inundated area (>= 0.3m) (km^2)		
		Average Flood 2005	Climate Change Condition	% increase due to CC
Faridpur	2072.72	643.3	723.5	12.47
Sirajganj	2497.92	1536.8	1709.2	11.21
Sunamganj	3669.58	2722.0	2841.0	4.37
Sathkhira	3858.33	2358.3	2409.5	-
Barisal	2790.51	1802.9	1946.8	8.00
Gaibandha	2179.27	999.0	1129.8	13.09
Pabna	2371.50	1386.9	1613.3	16.33

Increase of flood level and its duration are key factors to characterize the impact of flood due to climate change. It is seen that peak flood level has increased by about 37cm in a moderate flood event (2004 flood event) and in a normal flood event (2005 flood event) the increase is 27cm in the Jamuna river. Similar impacts are also seen in the Ganges river, where the increase of flood level is more than 50cm. The duration of flood at its danger level (danger level 19.5m, PWD as considered by FFWC) increases from 10 days to 16 days and flood level of 3 days duration (20m, PWD) prolongs to 8 days due to climate change in a moderate flood event in the Jamuna river, which is shown in Table E.5.

Table E.5: Change of flood level and duration due to increase of precipitation

Station	Duration of flood			Maximum Flood level			Maximum Flow		
	Flood Level (mPWD)	Flood Event		Flood Event		Depth increase in 2004	Flood Event		Flow increase in 2040
		Year 2004	Year 2040	Year 2004	Year 2040		Year 2004	Year 2040	
Bahadura-bad	19.5 (Danger Level)	10 days	16 days	20.19 mPWD	20.56 mPWD	37 cm	85,921 m^3/s	99,036 m^3/s	13,115 m^3/s
	20	3 days	8 days						
Sirajganj	13.75 (Danger Level)	17 days	19 days	14.81 mPWD	15.17 mPWD	36 cm	86,500 m^3/s	99,800 m^3/s	13,300 m^3/s
	14.5	6 days	10 days						
	14.7	3 days	8 days						
	15	0 days	3 days						

E.6 IMPACT ON LAND TYPE

Most of the cultivable lands in Bangladesh are subject to annual inundation. The time of flooding, depth, duration of flooding and rate of rise largely determine the choice and timing of crops. Impacts on land type will have implications on availability of land for cultivation of Transplanted Aman during monsoon. It is known that F0 and F1 land are suitable for T aman cropping, the decrease of F0 and F1 land may cause decrease of available land for T aman cropping.

Analysis shows that due to climate change F0 and F1 land decreases in most of the districts eventually availability of land for T aman in Khrif-II season may decrease gradually over the country. On the other hand deep inundated area i.e. F3 and F4 land increases considerably in all districts. It is seen decrease of F0 and F1 land is quite large in the Jamuna and the Ganges basin, which is in the range of 44% and 43% respectively, the coastal districts also shows similar decrease of F0 land. Impact on land type varies over the Kharif-II crop season i.e. from July to October. The availability of land area for T aman becomes extremely lesser in a moderate flood event compared to normal flood event in the Jamuna basin.

Available F0 and F1 land area are 3,200 ha and 23,000 ha for an average flood event, whereas in a moderate flood event the F0 and F1 land are 774 ha and 9,300 ha respectively in the Sirajganj district, which implies that land area for T aman crop would decrease considerably during a moderate flood event in future.

Table E.6: Impact on land type

Districts	Area (km^2)		Land Type				
			F0	F1	F2	F3	F4
Faridpur	2072.72	Inundation at 2005	32.04	156.60	289.80	186.57	10.35
		Inundation at 2040	33.66	163.71	308.79	240.66	10.35
		% increase	5.06	4.54	6.55	28.99	0.00
Sirajganj	2497.92	Inundation at 2005	58.23	401.49	699.21	423.90	12.24
		Inundation at 2040	32.13	230.76	694.31	748.71	35.37
		% increase	-44.82	-42.52	-0.70	76.62	3 hundred percent
Sunamganj	3669.58	Inundation at 2005	882.17	371.43	699.48	1178.10	472.95
		Inundation at 2040	65.16	324.54	672.30	1268.46	575.71
		% increase	-20.70	-12.62	-3.89	7.67	21.73
Satkhira	3858.33	Inundation at 2005	35.91	121.50	392.31	1844.37	0.09
		Inundation at 2040	27.72	127.70	216/00	2063.97	0.81
		% increase	-22.81	5.93	-44.94	11.91	Significant
Barisal	2790.51	Inundation at 2005	117.63	975.33	749.43	78.12	0.00
		Inundation at 2040	66.24	658.80	1161.81	126.18	0.00
		% increase	-43.69	-32.45	55.03	61.52	0.00
Gaibandha	2179.27	Inundation at 2005	74.43	414.81	479.79	104.04	0.36
		Inundation at 2040	73.44	333.27	570.87	224.73	0.90
		% increase	-1.33	-19.66	18.94	Significant	Significant
Pabna	2371.50	Inundation at 2005	61.56	219.96	487.08	553.68	126.18
		Inundation at 2040	55.35	198.90	410.94	721.98	281.52
		% increase	-10.09	-9.57	-15.63	30.40	Double

1. INTRODUCTION

1.1.1 Background

Bangladesh is a low-lying deltaic country in South Asia formed by the Ganges (Padma), the Brahmaputra (Jamuna) and the Meghna rivers and their respective tributaries. The country has been suffering from various types of major natural disasters like floods, cyclone, storm-surge, tidal bore, river bank erosion, salinity intrusion and drought etc. Currently climate change poses a new threat to life and livelihood of the people of Bangladesh. Climate change is recognized as a key sustainable development issue for Bangladesh (World Bank, 2000). These risks will be additional to the challenges the country already faces. Long-term changes in temperature and precipitation may impact agriculture yields. Changes in the onset, duration, and magnitude of the yearly monsoon season and consequent characteristics of floods, droughts, and cyclones are critical to the performance of the sector. Sea level rise may have severe implications on livelihood and productivity of coastal area through inundation and salinity.

The country is extremely vulnerable to climate change because of its geophysical settings. Bangladesh is a low-laying, flat country with big inland water bodies, including some of the biggest rivers in the world. Flooding is an annual recurring event during monsoon and 80% of annual rainfall occurs during monsoon. The total drainage area of GBM basin is 1.75 million sq.km and the average annual water flow is 1350 billion cubic meters, which is drained through Bangladesh but the GBM basin area within Bangladesh is only about 7-10% of the total area. If rainfall increases due to climate change in the GBM basin that will create huge water flow through the rivers of Bangladesh. So, the monsoon flood will be more devastating due to increase of precipitation and sea level rise.

Climate Change Cell (Component 4b of Comprehensive Disaster Management Programme) of Department of Environment has engaged IWM to carry out the impact assessment of climate change (causing increased rainfall and sea level rise) on monsoon flooding based on the recommendations of the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC).

The Fourth IPCC report approved in 2007 described the current state of understanding of the climate system and provides estimates of its projected future evolution and their uncertainties.

1.2 Study Area

The study area covers seven districts of Bangladesh namely Sirajganj, Gaibandha, Pabna Faridpur, Sunamganj, Satkhira and Barisal. The impact of climate change may be different in Jamuna, Ganges and Meghna basins and in the coastal area due to different flooding pattern in these basins. Considering the different nature of flood problems in the different region of Bangladesh seven districts have been selected to examine the change of flood regime and land type due to climate change. Faridpur, Gaibandha and Sirajganj represent Brahmaputra basin and Pabna is in Ganges basin. Satkhira and Barisal represent the coastal area that experience tidal and monsoon flooding. Sunamganj is characterised by haors and lies in the Meghna basin where flash flood is dominant. Among these districts Faridpur, Sirajganj, Sunamganj and Satkhira are the CDMP Pilot districts. This selection has been made in consultation with the official of the Climate Change Cell (CCC). The upazilas under these districts have been presented in the Table 1.1 and shown in the Figure 1.1.

Table 1.1: Upazilas of selected districts

District	Upazilas	Nos.
Faridpur*	Faridpur Sadar, Boalmari, Alfadanga, Madhukhali, Bhanga, Nagarkanda, Char Bhadrasan and Sadarpur	8
Sirajganj*	Belkuchi, Chauhali, Kamarkhanda, Kazipur, Raiganj, Shahjadpur, Sirajganj Sadar, Tarash and Ullahpara	9
Sunamganj*	Bishwamvarpur, Chhatak, Derai, Dharmapasha, Dowarabazar, Jagannathpur, Jamalganj, Tahirpur, Sullah and Sunamganj Sadar	10
Satkhira*	Satkhira Sadar, Assasuni, Debhata, Kalaroa, Kaliganj, Shyamnagar and Tala	7
Barishal	Agailjhara, Babuganj, Bakerganj, Banaripara, Gournadi, Hizla, Barisal Sadar, Mehendiganj, Muladi and Wazirpur	10
Gaibandha	Fulchhari, Gaibandha Sadar, Gobindaganj, Palashbari, Sadullapur, Sughatta and Sundarganj	7
Pabna	Atgharia, Bera, Bhangura, Chatmohar, Faridpur, Ishwardi, Santhia, Sujanagar and Pabna Sadar	9

* CDMP Pilot districts

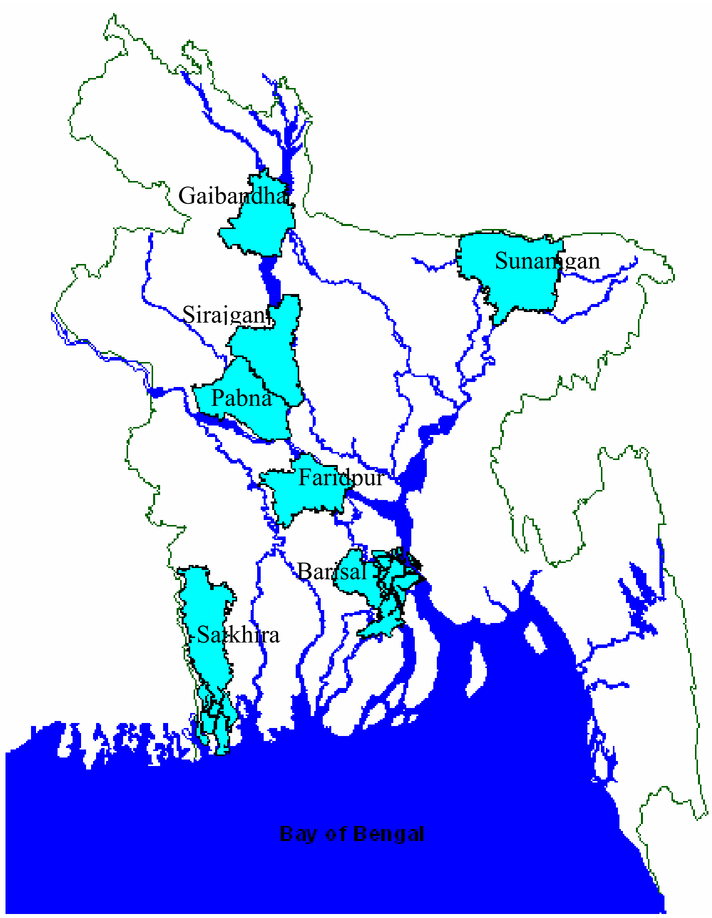

Figure 1.1: Map of the study area

1.3 Review of Past Studies

A number of studies on impact assessment of climate change and sea level rise had been carried out in the past. Some of the relevant past study reports have been reviewed to find the findings of earlier studies:

4th IPCC, Technical Summary, 2007, "A Report of Working Group I of the Intergovernmental Panel on Climate Change"

In the six years since the IPCC's Third Assessment Report (TAR), significant progress has been made in understanding past and recent climate change and in projecting future changes. These advances have arisen from large amounts of new data, more sophisticated analyses of data, improvements in the understanding and simulation of physical processes in climate models and more extensive exploration of uncertainty ranges in model results.

The dominant factor in the radiative forcing of climate in the industrial era is the increasing concentration of various greenhouse gases in the atmosphere. Several of the major greenhouse gases occur naturally but increases in their atmospheric concentrations over the last 250 years are due largely to human activities.

Long-Lived Green House Gases (LLGHGs), for example, CO_2, methane (CH_4) and nitrous oxide (N_2O), are chemically stable and persist in the atmosphere over time scales of a decade to centuries or longer, so that their emission has a long-term influence on climate.

The concentration of atmospheric CO_2 has increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005. The CH_4 abundance in 2005 of about 1774 ppb is more than double of its pre-industrial value. The N_2O concentration in 2005 was 319 ppb, about 18% higher than its pre-industrial value. Over the 1961 to 2003 period, the average rate of global mean sea level rise is estimated from tide gauge data to be 1.8 ± 0.5 mm yr^{-1}.

Projected global average surface warming and sea level rise at the end of the year 2100 based on AOGCMs is presented in the following table.

Item	Scenarios					
	B1	A1T	B2	A1B	A2	A1Fl
Temperature	1.1 – 2.9	1.4 – 3.8	1.4 – 3.8	1.7 – 4.4	2.0 – 5.4	2.4 – 6.4
Sea Level Rise	0.18 – 0.38	0.20 – 0.45	0.20 – 0.43	0.21 – 0.48	0.23 – 0.51	0.26 – 0.59

Projected precipitation change in Southeast Asia during the 21st century based on AOGCMs is presented in the table below.

Sub-regions	Season	2010 - 2039		2040 - 2069		2070 - 2099	
		Scenarios					
		A1Fl	B1	A1Fl	B1	A1Fl	B1
South Asia	DJF	-3	4	0	0	-16	-6
	MAM	7	8	26	24	31	20
	JJA	5	7	13	11	26	15
	SON	1	3	8	6	26	10

Note[1]: A1 Scenario – based on homogeneous world of very rapid economic growth, high global population that peaks in mid-century and the rapid introduction of new and more efficient technologies. It represents a convergent world with a substantial reduction in regional per capita income. Based on emission it is divided into three categories such as A1Fl, A1T and A1B. A1Fl – Based on fossil fuel intensive – represent very high emission

B1 Scenario: based on convergent world with the same global populations as in A1 but with rapid change in economic structures and the introduction of clean and resource-efficient technologies. Special emphasis is given on global solution to economic, social and environmental sustainability including improved equity. It represents very low emission.

Note[2]: DJF: December, January & February; MAM: March. April & May; JJA: June, July & August; SON: September, October &November (-ve: decrease)

If radiative forcing were to be stabilised in 2100 at A1B concentrations, thermal expansion alone would lead to 0.3 to 0.8 m of sea level rise by 2300.

Recent studies with improved global models, ranging in resolution from about 100 to 20 km, suggest future changes in the number and intensity of future tropical cyclones (typhoons and hurricanes).

BWDB, 2007, "Real Time Data Collection (July '05 to December '06) for FFWC and Update & Model Validation of General/ National & 6-Regional Models for 2003-06 Hydrological Year"

The study has been aimed at supporting Flood Forecasting and Warning Centre (FFWC) in carrying out its regular flood forecasting activities and updating the General and Regional Models. Continuous supply of real time data to FFWC during the flood season is essential for timely delivery of routine flood bulletin and other associated information. IWM was also assigned the duties of collecting and transmitting real time data during the implementation of validation of models. Updated and validated General and six Regional Models and its databases have been transferred to FFWC, BWDB and all model results and data will be archived for future use and reference after the end of the project. The models are suitable for macro-level studies like feasibility study of water sector projects, flood forecasting needs and flood management in Bangladesh. The models used in this study are as follows.

- General Model (GM)
- South East Region Model (SERM)
- South West Region Model (SWRM)
- North West Region Model (NWRM)
- North Central Region Model (NCRM)
- North East Region Model (NERM)
- Eastern Hilly Region Model (EHRM)

IWM, 2007"Investigating the Impact of Relative Sea-Level Rise on Coastal Communities and their Livelihoods in Bangladesh"

The study has made a detailed assessment of the potential impacts of relative sea-level rise (resulting from global climate change, changes in river-flow and coastal development) on coastal populations, socio-economic impacts on livelihoods of coastal communities of Bangladesh. The study considered the sea level rise, changes in intensity of cyclones and precipitation for both low (B1) and high (A2) greenhouse gas emission scenarios according to the 3rd IPCC predictions.

The study shows that about 16% more area (551,000 ha) in the coastal region will be inundated in monsoon due to 62 cm sea level rise and 10% increased rainfall for high emission scenario A2 in addition to the inundated area in base condition. And the most vulnerable areas are the areas without polders like Patuakhali, Pirojpur, Barisal, Jhalakati, Bagerhat, Narail.

The study also found that about an additional area of 327,700 ha would become high saline water zone (>5 ppt) during dry season due to 62 cm sea level rise as predicted in IPCC 3rd an present report. In the monsoon about 6% of sweet water area (276,700 ha) will be lost.

The other main outcomes of the study were as follows:

- Due to 27 cm SLR and increased cyclone intensity in 2050, Chittagong district will be affected more and about 99,000 ha more area (18%) will be exposed to severe inundation (>100cm). Moreover, about 35,000ha area of Cox's Bazar district will be inundated severely (>100cm) compared to 1991 cyclone inundation.

- In year 2080 under low emission scenario B1, about 44% people will be exposed to additional flooding due to 15 cm SLR and for high emission scenario (A2) at 62 cm SLR, exposure will be 51% of population in additional inundated area.
- Concerning food security, the per capita food grain availability will reduce from 574 gm/person/day to 265 gm/person/day and to 207 gm/person/day in years 2050 and 2080 respectively under A2 scenario. For the same years under B1 scenario the availability will be 375 gm/person/day and 385 gm/person/day.
- Agriculture contributes about 30% to the GDP in coastal area. This contribution will decrease by 2.1% and 3% in years 2050 and 2080.
- Farmer's farming opportunity will decrease by 13.5% and 25.1% in years 2050 and 2080 respectively under the scenario A2, but under scenario B1 this decrease will be less (9.6% and 13.4%).
- Fishermen's fishing opportunity will decrease by 8% and 15% in same years under scenario A2, whereas under scenario B1 the decreases will be about 6% and 8%.
- The vulnerable group women mainly depend on livestock, cottage industries and male family members. About 7.72 million and 19.9 million women will be economically and socially vulnerable due to reduction of suitable area of livestock in years 2050 and 2080 respectively.

However, the study did not carry out any analysis on the change of monsoon flooding due to increase of precipitation in the upper region of the country.

3rd IPCC, Summary for Policymakers, "A Report of Working Group I of the Intergovernmental Panel on Climate Change" 2001

The Third Assessment of Working Group I of the Intergovernmental Panel on Climate Change (IPCC) was built upon past assessments and incorporate new results from the past five years of research on climate change. The summary report describes the current state of understanding of the climate system and provides estimates of its projected future evolution and their uncertainties. In order to make projections of future climate, models incorporated past, as well as future emissions of greenhouse gases and aerosols. *Projections of global average sea level rise from 1990 to 2100, using a range of AOGCMs (*Atmosphere-Ocean General Circulation Model) *following the IS92a (Illustrative Scenarios 1992) scenario (including the direct effect of sulphate aerosol emissions), lie in the range 0.11 to 0.77 m.* This range reflects the systematic uncertainty of modelling. The main contributions to this sea level rise are:

- a thermal expansion of 0.11 to 0.43 m, accelerating through the 21st century;
- a glacier contribution of 0.01 to 0.23 m;
- a Greenland contribution of -0.02 to 0.09 m and
- an Antarctic contribution of -0.17 to +0.02 m.

For the full set of SRES scenarios, a sea level rise of 0.09 to 0.88 m is projected for 1990 to 2100, primarily from thermal expansion and loss of mass from glaciers and ice caps. The report also projected that warming associated with increasing greenhouse gas concentrations will cause an increase of Asian summer monsoon precipitation variability.

Globally averaged water vapour, evaporation and precipitation are projected to increase. At the regional scale both increases and decreases in precipitation are seen. Results from recent AOGCM (Atmosphere-Ocean General Circulation Model) simulations forced with SRES (Special Report on Emissions Scenarios) emissions scenarios indicate that it is likely for precipitation to increase in both summer and winter over high-latitude regions. In winter, increases are also seen over northern mid-latitudes, tropical Africa and Antarctica, and in summer in southern and eastern Asia. Australia, central America, and southern Africa show consistent decreases in winter rainfall.

It is only recently that changes in extremes of weather and climate observed to date have been compared to changes projected by models. More hot days and heat waves are very likely over nearly all land areas. These increases are projected to be largest mainly in areas where soil moisture decreases occur. Increases in daily minimum temperature are projected to occur over nearly all land areas and are generally larger where snow and ice retreat.

Some of the global climate models suggest an increase in tropical storm intensities with CO_2 induced warming (Krishnamurti et al., 1998), though a limitation of that study is the short two years model run.

OECD, 2003 "Development and climate change in Bangladesh: Focus on coastal flooding and the Sundarbans."

An output from the OECD (Organization for Economic Co-operation and Development) Development and Climate Change project, an activity being jointly overseen by the Working Party on Global and Structural Policies (WPGSP) of the Environment Directorate, and the Network on Environment and Development Co-operation of the Development Co-operation Directorate. The study projected the climate change and sea level rise for Bangladesh. For precipitation and temperature change projection, 17 GCMs (Global Circulation Model) developed since 1995 were examined for Bangladesh. For the changed frequency and intensity of cyclones, with references of 3rd IPCC report, the study concludes an increase in peak intensity may be in the range of 5-10%. The study referred to the 3rd IPCC findings on global change for sea level rise.

PDO-ICZM, 2004 "Where land meets the sea – A Profile of the Coastal Zone of Bangladesh" published by PDO-ICZM, WARPO.

The project has focused on the likely climate change scenarios of Bangladesh. The report states that efforts have been made to quantify climate changes in Bangladesh. From analysis of 22 years water level data (1977 – 1998), SLR has been estimated as 7.8 mm/year, 6.0 mm/year and 4.0 mm/year at Cox's Bazar, Char Chenga and Hiron Point respectively (SMRC 2000a, 2000b). Projected precipitation fluctuations are -1.2% to -3.0% in winter from 2030 to 2100 and +4.7% to +11.8% in monsoon for 2030 to 2100.

"***Considering Adaptation to Climate Change in the Sustainable Development of Bangladesh."***

This is a study carried out in 1999, a combined effort of BCAS, CEARS, University of Waikato, Resource Analysis, SASRD and World Bank. The general objective of the study was to reduce the vulnerability of Bangladesh for impacts of possible climate change. The study has outlined likely scenarios of climate change and is based on the findings of 2nd IPCC. The study identified critical impacts on drainage congestion problem, reduction in fresh water flow, and disturbance of morphologic processes, increase intensity of disasters. And finally it has recommended approaches and challenges in adapting to climate change.

WARPO, 2005 "Impact Assessment of Climate Change on the Coastal zone of Bangladesh"

The study has made a detailed assessment of Impacts of sea level rise on inundation, drainage congestion, salinity intrusion and change of surge height in the coastal zone of Bangladesh. Sea level rise has been considered as the main variables of climate change, quantification of which is based on the recommendations of the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) and NAPA (National Adaptation Program of Action) scenarios. The potential effects of climate change were studied for different sea level rise i.e.14 cm, 32 cm, and 88 cm for the project years 2030, 2050 and 2100. Mathematical models of the Bay of Bengal have been used to transfer the sea level rise in the deep sea along the southwest region rivers and the Meghna Estuary.

The main outputs of findings of the study are summarized below:

- About 11% more area (4,107 sq.km) will be inundated due to 88 cm sea level rise in addition to the existing (year 2000) inundation area under the same upstream flow. Sea would enter more landward and at Chandpur water level will rise by 50 cm for 88 cm rise of sea level and 15 cm for 32 cm rise of sea level.
- 5 ppt saline front moves landward remarkably for sea level rise of 88 cm. In the southeast corner of the area (including Sundarbans) 4 ppt isohaline moves further inland by 4 km and 12 km due to sea level rise of 32cm and 88cm respectively. In the middle part of area the landward movement with this isohaline be within the range of 6 to 8 km for the same level of sea level rises. Salinity in Khulna will increase by 0.5 to 2 ppt for the 32 cm and 88 cm sea level rise.
- About 84% of the Sundarbans area becomes deeply inundated due to 32 cm sea level rise, and for 88 cm sea level rise Sundarbans will be lost.
- A significant number of coastal polders will be facing acute drainage congestion due to sea level rise.
- Due to 32 cm sea level rise, surge height will increase in the range of 5 to 15% in the eastern coast. It has been also observed that 10% increase in wind speed of 1991 cyclone along with 32 cm sea level rise would produce 7.8 to 9.5 m high storm near Kutubdia-Cox's Bazar coast.

WARPO, 2005 "Formulation of Bangladesh Program of Action for Adaptation to Climate Change Project"

As a party to the UNFCCC, the Government of Bangladesh (GoB) has instituted the preparation of the National Adaptation Program of Action (NAPA) for the country. Taking a sectoral approach, a concerted Sectoral Working Group (SWG) concept has been undertaken to develop the Bangladesh NAPA. The important task of developing sectoral NAPA has been assigned to these SWGs that will ultimately be helpful in devising the BDNAPA. Water

Resources Planning Organization (WARPO) was assigned to coordinate the BDNAPA activities for four sub-sectors namely: Water, Coastal Areas, Natural Disaster and Health.

The sectoral NAPA came up with 9 different proposed projects that are prioritized based on urgency and immediacy of the four sub-sectors of the SWG. These are as follows:

Water:

(i) Climate change knowledge gap filling for water resources planning.

(ii) Development of capacity building tools for designing structural adaptation.

(iii) Development of negotiating instruments for sustainable drainage systems.

Coastal Areas:

(iv) Reduction of climate change hazards through community based afforestation.

(v) Land and water use zoning for climate change adaptation.

Natural Disaster:

(vi) Increase awareness and dissemination of climate change issues of standing orders on disasters (SOD) preparedness in Bangladesh.

(vii) Redesigning and strengthening of multipurpose cyclone/flood shelters in high vulnerable areas.

Health:

(viii) Development of alternative sources of safe drinking water in saline prone areas.

(ix) Awareness and behavioral change and communication for climate change related health problems.

1.4 Objective

The main objective of the present study is to assess the impact on flooding during monsoon due to climate change. The specific objectives are:

- To assess the impact on flooding at local level (Upazila) due to increase of precipitation and sea level rise based on 4th IPCC report for South Asia (AR4, 2007) for the year 2040.

1.5 Output

The expected outputs of the study are as follows:

- Existing condition of flood (baseline as on 2005)
- Increased flooding area due to climate change (2040) for average and moderate flood event.
- Inundation depth and duration map for each Upazila (2040)
- Combined effect of increased precipitation and Sea Level Rise (SLR) on flooding in the selected coastal districts (2040)
- Predicted frequency of severe flood (like 1988/1998/2004) following climate change

2. DATA and MODEL

2.1 Data Collection and Compilation

Reliable data are prerequisite to carry out flood frequency analysis, establish base conditions on floods and land type. Available water level and water flow time series, river bathymetry and rainfall data were collected from secondary sources such as BWDB and BIWTA. Bathymetry data were collected to develop and update the model bathymetry of Bay of Bengal and other regional models Water level data and discharge data were collected to generate boundaries and to re-calibrate the existing models. Rainfall data were collected for development of rainfall-runoff model (NAM model). Coverage area of T-Aman in three selected upazilas Bakerganj of Barisal district, Raiganj of Sirajganj district and Gobindaganj of Gaibandha district has been collected in consultation with each block supervisor of corresponding upazila.

2.2 Available Models

2.2.1 GBM Basin Model

Background

The country's unique geographical location with the Indian Ocean to the South, the Himalayas to the north and the prevailing monsoons has made it one of the wettest countries of the world. Bangladesh is probably the worst victim of excessive rainfall in the upper catchment outside its territory. This external rainfall generates massive runoff of water that reaches the Bay of Bengal through country's territory. Almost all the major rivers have their origins beyond the political border of the country, and thereby placing it in a disadvantageous position to manage its own river systems.

There are 57 border rivers bringing inflows from India. About one-fourth to one-third of the country is normally flooded to varying degrees each year during the period from May through September. The major flood of 1998 caused inundation of about 70 % of the country. This figure of flooding is expected to be more severe in future due to climate change and sea level rise.

The GBM basin model was applied to reproduce the possible changes of monsoon flood in the basin resulting from predicted hydro meteorological changes in the area. IWM carried out this study through updating a previously developed simplified GBM basin model incorporating up to date information. The model was used to compute runoffs generated from basins of three major rivers, and thereby simulate the scenarios regarding monsoon flood in the country introducing subsequent effect of climate change.

The prime objective of this study component "Updating of the GBM basin model" is quantification of inflows generated from three major river basins under recent & changed climate condition so that impact on monsoon flooding in Bangladesh resulting from climate change and sea level rise as predicted in 4th assessment report of IPCC can be studied.

Activities

The GBM basin model available at IWM, likely to be a well-suited tool for studying basin hydrological process, requires updating for application in water resource planning and management. The specific scope of works regarding this component of the study includes:

- re-delineation of sub-basins
- procure baseline information of the basin
- procure hydro meteorological data of the basin area
- increase performance of model
- scenario simulation regarding climate change

Approach and Methodology

The Ganges-Brahmaputra-Meghna river (GBM) basin comprises intensively varied topographic, meteorological and hydrological characteristics. Rational method of runoff computation seems to be a very crude approach for this large and geographically complex basin. Hence, application of mathematical model was considered to be appropriate for proper estimation of runoff. A mathematical model of the GBM basin developed in MIKE BASIN platform available at IWM was in a very preliminary stage. The base model was updated incorporating latest available information including follow up of conclusive recommendations deduced in the first development stage. The basin runoffs were estimated using GBM basin model for different available rainfall sets. Basin runoffs regarding predicted climate change scenario were simulated incorporating rainfall change predicted in 4th Assessment Report of IPCC. The methodology adopted in the study has been described in the following sections.

Base Model Development

The existing GBM basin model was updated incorporating latest available data and information including re-delineation of sub-catchments. The performance and sensitivity of the model were scrutinized using different sets of parameters and input data. Parameters were optimized through series of trial simulations. The base model was developed giving priority on ground measured rainfalls.

Basin Runoff Computation

After developing database and base model, basin runoffs were computed for average year hydrological event through simulation of base model. Basin runoffs in predicted climate change scenario were computed incorporating changed precipitation where change in evaporation and temperature were overlooked.

River System

The GBM river system comprises three major rivers: the Ganges, the Brahmaputra, and the Meghna. The River system has been described below:

Ganges

Ganges basin includes six tributaries: the Ganges, the Yamuna, the Son, the Ghagra, the Gandhak and the Koshi; each of which is itself a small river system.

The Yamuna

The Yamuna (sometimes called Jamuna or Jumna) is a major tributary river of the Ganges (Ganga) in northern India. With a total length of around 1,370 kilometers (851 mi), it is the largest tributary of the Ganges (Ganga). Its source is at Yamunotri, in the Uttarakhand Himalaya, which is north of Haridwar in the Himalayan Mountains. It flows through the states of Delhi, Haryana and Uttar Pradesh, before merging with the Ganges at Allahabad. The cities of Delhi, Mathura and Agra lie on its banks. The major tributaries of this river are the Tons, Chambal, Betwa, and Ken; with the Tons being the largest.

The Ganges

The Ganges originates in the Himalayas after the confluence of six rivers – Alaknanda meets Dhauliganga at Vishnuprayag, Mandakini at Nandprayag, Pindar at Karnaprayag, Mandakini at Rudraprayag and finally Bhagirathi at Devaprayag (from here onwards, it is known as Ganga) in the Indian state of Uttarakhand. Out of the five, the Bhagirathi is held to be the source stream originating at the Gangotri Glacier at an elevation of 7,756 m (25,446 ft). The streams are fed by melting snow and ice from glaciers including glaciers from peaks such as Nanda Devi and Kamet. After travelling 200 km through the Himalayas, the Ganges emerges at the pilgrimage town of Haridwar in the Shiwalik Hills. At Haridwar, a dam diverts some of its waters into the Ganges Canal, which links the Ganges with its main tributary, the Yamuna. The Ganges which till this point flows in a south-western direction now begins to flow in a south-eastern direction through the plains northern India. From Haridwar the river follows an 800 km (500 mi) winding course passing through the city of Kanpur, before being joined by the Yamuna from the southwest at Allahabad. This point, the confluence of the three rivers, known as the Sangam, is a sacred place in Hinduism.

Joined by numerous rivers such as the Kosi, Son, Gandak and Ghaghra, the Ganges forms a formidable current in the stretch between Allahabad and Malda in West Bengal. On its way it passes the towns of Mirzapur, Varanasi, Patna and Bhagalpur. At Bhagalpur, the river meanders past the Rajmahal Hills, and begins to change course southwards. At Pakaur, the river begins its first attrition with the branching away of its first distributary, the River Bhagirathi, which goes on to form the River Hooghly. Close to the border with Bangladesh, the Farakka Barrage, built in 1974 controls the flow of the Ganges, diverting some of the water into a feeder canal linking the Hooghly to keep it relatively silt free.

After entering Bangladesh, the main branch of the Ganges is known as Padma River until it is joined by the Jamuna River the largest distributary of the Brahmaputra. Further downstream, the Ganges is fed by the Meghna River, the second largest distributary of the Brahmaputra and takes on its name entering the Meghna Estuary. Fanning out into the 350 km (220 mi) wide Ganges Delta, it empties out into the Bay of Bengal.

Brahmaputra

Originating from the great glacier mass of Chema-Yung-Dung in the Kailas range of southern Tibet at an elevation of 5,300 m., it traverses 1,625 km. in China and 918 km. in India, before flowing 337 km. through Bangladesh and emptying into the Bay of Bengal through a joint channel with the Ganga. In China, the river is known as the Yarlung Tsangpo, and flows east for about 1700 km, at an average height of 4000 m. At its easternmost point, it bends around

Mt. Namcha Barwa, and forms the Yarlung Tsangpo Canyon which is considered the deepest in the world.

As the river enters Arunachal Pradesh (India), it is called *Siang* and makes a very rapid descend from its original height in Tibet, and finally appears in the plains, where it is called *Dihang*. It flows for about 35 km and is joined by two other major rivers: Dibang and Lohit. From this point of confluence, the river becomes very wide and is called Brahmaputra. It is joined in Sonitpur District by the Jia Bhoreli (named the Kameng River where it flows from Arunachal Pradesh) and flows through the entire stretch of Assam. In Assam the river is sometimes as wide as 10 km. Between Dibrugarh and Lakhimpur districts the river divides into two channels-the northern *Kherkutia* channel and the southern Brahmaputra channel. The two channels join again about 100 km downstream forming the Majuli island. At Guwahati near the ancient pilgrimage centre of Hajo, the Brahmaputra cuts through the rocks of the Shillong Plateau, and is at its narrowest at 1 km bank-to-bank.

In Bangladesh, the Brahmaputra splits into two branches: the much larger branch continues due south as the Jamuna (*Jomuna*) and flows into the Lower Ganges, locally called Padma (*Pôdda*), while the older branch curves southeast as the lower Brahmaputra (*Bromhoputro*) and flows into the Meghna. Both paths eventually reconverge near Chandpur in Bangladesh and flow out into the Bay of Bengal. Fed by the waters of the Ganges and Brahmaputra, this river system forms the Ganges Delta, the largest river delta in the world (Ref. 4).

Meghna

The Barak River is the major river of northeastern India and part of the Surma-Meghna River System. It rises in the Manipur hills and enters the plains near Lakhipur. Downstream of Silchar town and before entering Bangladesh the Barak bifurcates into the Surma River and the Kushiyara River. The principal tributaries of the Barak in India are the Jirl, the Dhaleshwari, the Singla, the Longai, the Sonai and the Katakhal. From its source in the Manipur Hills near Mao Songsang, the river is known as the Barak River. It flows west through Manipur State, then southwest leaving Manipur. In Mizoram State it flows southwest then veers abruptly north when joined by a north flowing stream and flows into Assam State where it turns westward again near Lakipur and flows west past the town of Silchar where it enters Bangladesh.

The Meghna is an important river in South Asia, and one of the three rivers that flow into the Ganges delta. The river meets Padma River in Chandpur District. The river ultimately flows into the Bay of Bengal in Bhola District. Only two rivers, the Amazon and the Congo have a higher discharge than the combined flow of the Ganges, the Brahmaputra and the Surma-Meghna river system.

River Basin

The GBM basin is located between 22 degree 3.5 minutes and 31 degree 50 minutes north latitudes, and 73 degree 10.5 minutes and 97 degree 53 minutes east longitudes. Topographically it is extended in three characteristic areas: the Hindukush Himalaya, the Ganges Delta and the Peninsular Basin of central India. The Basin comprises three independent river basins: the Ganges basin, the Brahmaputra basin, and the Meghna basin. The details of the basins have been described below:

Ganges Basin

The Upper Ganges basin comprses a basin area of 965,000 sq. km considering the basin concentration point is located at Hardinge Bridge, Bangladesh. The bulk of the basin area is located in India and the rest in Nepal and China. The Lower Ganges Basin comes under the jurisdiction of the greater districts of Kushtia, Jessore, Faridpur, Khulna, Barisal, and Patuakhali of Bangladesh. It comprises an area of approximately 40,450 km^2, or 27 per cent of Bangladesh's total area.

The Gangotri Glacier in the Uttaranchal Himalayas is the origin of the Bhagirathi river, which joins the Alaknanda river at Devaprayag, also in the Uttaranchal Himalayas, to form the Ganga. The river then flows through the Himalayan valleys and emerges into the north Indian plain at the town of Haridwar. The Ganga then flows across the broad plains of north India (called the Gangetic Plains) and forms the major river basin of that vast region. The tributaries of Ganga include the Ramganga, the Sai, the Gomati, the Sone, the Yamuna, the Mahananda, the Ghagra, the Rapti, the Gandhak, the Buri Gandhak, and the Ghugri. The last five tributaries are originated from Himalayas in Nepal and Tibet of China, and joined the Ganga following through India. After meeting the Yamuna, the Ganges bypasses the Mirzapur Hills and Rajmahal Hills to the south and flows southeast to Farakka, at the apex of the delta. In Bangladesh the Ganges is joined by the mighty Brahmaputra near Goalundo Ghat. The combined stream, is called the Padma, joins with the Meghna river above Chandpur. From Devprayag to the Bay of Bengal and the vast Sunderbans delta, the Ganga flows some 2500 km, passing (and giving life to) some of the most populous cities of India and Bangladesh.

Brahmaputra Basin

The Brahmaputra is a major international river covering a drainage area of 580,000 sq. km. 50.5 percent of which lies in China, 33.6 percent in India, 8.1 percent in Bangladesh and 7.8 percent in Bhutan. Its basin in India is shared by Arunachal Pradesh (41.88%), Assam (36.33%), Nagaland (5.57%), Meghalaya (6.10%), Sikkim (3.75%) and West Bengal (6.47%). Originating in a great glacier mass in the Kailas range in southern Tibet at an elevation of 5300m, the Brahmaputra flows through China (Tibet), India and Bangladesh for a total distance of 2880 km before emptying itself into the Bay of Bengal through a joint channel with the Ganga.

The Brahmaputra basin, as a whole, has a forest cover of about 14.5%, grasslands occupy about 44%, agricultural lands about 14%, cropland/natural vegetation mosaic 12.8%, barren/sparsely vegetated land 2.5%, water bodies 1.8%, snow and ice 11%, urban land 0.02% and permanent wetlands 0.05%. The total forest cover of the Brahmaputra basin in India is 1,14,894 sq. km. i.e. 54% of the total area. The distribution of forest cover in the different states within the Brahmaputra basin is as follows: Arunachal Pradesh (82.8%), Nagaland (68.9%), Meghalaya (63.5%), Sikkim (38.1%), West Bengal (21.4 %) and Assam (20.6 %). As a whole, the eastern Himalaya is more humid, its climate more conducive to tree growth with a relatively higher tree line (average 4,570 m.) compared to the western and central Himalayas.

Meghna Basin

The Meghna Basin comprises an area about 75500 sq. km. out of which around 68 % area lies within India. The Meghna is formed inside Bangladesh by the joining of different rivers originating from the hilly regions of eastern India.

Topography

The Ganges basin comprises three distinct characteristic lands stretched on east-west direction: the Himalayas and associated ranges on the north; the peninsula hills on the south; and the great trench between the Peninsula and the Himalayas, the largest alluvial plain on earth. (http://www.nationsencyclopedia.com/Asia-and-Oceania/India-TOPOGRAPHY.html).

The Brahmaputra River drains diverse environments as the cold dry plateau of Tibet, the rain-drenched Himalayan slopes, the landlocked alluvial plains of Assam and the vast deltaic lowlands of Bangladesh.

Climate

The Ganges basin is subjected to a humid sub-tropical climate. The year can be divided into four seasons: the relatively dry, cool winter from December through February; the dry, hot summer from March through May; the southwest monsoon from June through September when the predominating southwest maritime winds bring rains to most of the country; and the northeast, or retreating, monsoon of October and November.

The Himalayas, along with the Hindu Kush mountains in Pakistan, prevent cold Central Asian katabatic winds from blowing in, keeping the bulk of the Indian subcontinent warmer than most locations at similar latitudes. There is very little precipitation during the winter, owing to powerful anticyclonic and katabatic (downward-flowing) winds from Central Asia. the two Himalaya states of India: Himachal Pradesh, and Uttarakhand experience heavy snowfall. The mean temperatures are 10–15 °C (50–59 °F) in Himalayas ranges. Winter highs in Delhi range (Western part of Ganges) from 16 °C (61 °F) to 21 °C (70 °F). Nighttime temperatures average 2–8 °C (36–46 °F). The Indo-Gangetic Plain, almost never receives snow. However, in the plains, temperatures occasionally fall below freezing, though never for more one or two days. Eastern India's climate (eastern part of Ganges basin) is much milder, experiencing moderately warm days and cool nights. Highs range from 23 °C (73 °F) in Patna to 26 °C (79 °F) in Kolkata (Calcutta); lows average from 8 °C (46 °F) in Patna to 14 °C (57 °F) in Kolkata. Frigid winds from the Himalayas can depress temperatures near the Brahmaputra River. The two Himalayan states in the east, Sikkim and Arunachal Pradesh, receive substantial snowfall. The extreme north of West Bengal, centred around Darjeeling, also experiences snowfall, but only rarely. Winter rainfall—and occasionally snowfall—is associated with large storm systems such as "Nor'westers" and "Western disturbances"; the latter are steered by westerlies towards the Himalayas.

Summer in the GBM basin lasts from March to June. The temperatures in the north rise as the vertical rays of the Sun reach the Tropic of Cancer. The hottest month for most of the basin is May. In cooler regions of North India, immense pre-monsoon squall-line thunderstorms, known locally as "Nor'westers", commonly drop large hailstones. Most summer rainfall occurs during powerful thunderstorms associated with the southwest summer monsoon; occasional tropical cyclones also contribute.

The southwest summer monsoon, a four-month period, when massive convective thunderstorms dominate the weather in the basin. It originates from a high-pressure mass centered over the southern Indian Ocean; attracted by a low-pressure region centered over South Asia, it gives rise to surface winds that ferry humid air into basin from the southwest. These inflows ultimately result from a northward shift of the local jet stream, which itself results from rising summer temperatures over Tibet and the Indian subcontinent. The void left by the jet stream, which switches from a route just south of the Himalayas to one tracking north of Tibet, then attracts warm, humid air.

The main factor behind this shift is the high summer temperature difference between Central Asia and the Indian Ocean. The southwest monsoon blows in from sea to land occurring in two branches: the Arabian Sea monsoon and the Bay of Bengal monsoon. The Arabian Sea monsoon usually breaks on the west coast early in June bringing cooler but more humid weather, and reaches the north-west area of the Ganges basin by the first week in July. On the other hand, the other branch, known as the Bay of Bengal monsoon, moves northward in the Bay of Bengal and spreads over most of Assam (Brahmaputra and Meghna Basin) by the first week of June. On encountering the barrier of the Great Himalayan Range, it is deflected westward along the Indo-Gangetic Plain (i.e. over the Ganges basin) toward New Delhi (North-west of Ganges basin). Thereafter the two branches merge as a single current bringing rains to the Ganges basin in July.

Annual rainfall ranges from less than 1,000 millimetres (39 in) in the west to over 2,500 millimetres (98 in) in parts of the northeast. As most of this region is far from the ocean, the wide temperature swings more characteristic of a continental climate predominate; the swings are wider than in those in tropical wet regions, ranging from 24 °C (75 °F) in north-central India to 27 °C (81 °F) in the east.

Hydrology

The annual regime of river flow in Ganges and Brahmaputra basin is controlled by climatic conditions. Rivers flowing from the Himalayas experience two high-water seasons, one in early summer caused by snow melt in the mountains, and one in late summer caused by runoff from monsoon rains. Nearly 70% of discharge to the River Ganges comes from Nepalese snow-fed rivers.

The Ganges basin contains the largest river system in the subcontinent. The water supply is dependent partly on the rains brought by the southwesterly monsoon winds from July to October, as well as on the flow from melting Himalayan snows, in the hot season from April to June. Precipitation in the river basin accompanies the southwest monsoon winds, but it also comes with tropical cyclones that originate in the Bay of Bengal between June and October. Only a small amount of rainfall occurs in December and January. The average annual rainfall varies from 30 inches (760 millimetres) at the western end of the basin to more than 90 inches at the eastern end. (In the upper Gangetic Plain in Uttar Pradesh rainfall averages about 30 to 40 inches, in the Middle Plain of Bihar from 40 to 60 inches, and in the delta region between 60 and 100 inches.

The Brahmaputra basin, excluding the Tibetan portion, forms an integral part of the southeast Asian monsoon regime with a mean annual rainfall of 2,300 mm. Distribution of rainfall over the basin varies from 1,200 mm. in parts of Nagaland to over 6,000 mm. on the southern slopes of the Himalaya. The Himalayas exercise a dominating influence on the prevailing weather of the basin due to their location in the path of the southwest monsoon. Rainfall in the Himalayan sector averages 500 cm. per year with the lower ranges receiving more. A gradual increase in rainfall from the valley bottom towards the lower ranges followed by a decrease towards the higher ranges is evident from the annual rainfall at Dibrugarh (2,850 mm.) in the far eastern part of Assam valley, Pasighat (5,070 mm.) in the foothills and Tuting (2,740 mm.) further up the Himalayas. Monsoon rains from June to September account for 60-70% of the annual rainfall in the basin, while the pre-monsoon season from March through May produces 20-25% of the annual rainfall. Snowfall is experienced in the Brahmaputra basin in areas with elevations of 1,500 m. and above. There are altogether 612 glaciers in the Brahmaputra basin of which 450 are in the Teesta sub-basin of Sikkim while 162 are in the Kameng river (upper Jia Bharali) sub-basin of Arunachal Pradesh.

Snow and Ice

The Nepal Himalaya revealed 3,252 glaciers and 2,323 lakes above 3,500 m above sea level. They cover an area of 5,323 km^2 with an estimated ice reserve of 481 km^3. The Koshi River basin comprises 779 glaciers and 1,062 lakes. The glaciers in the basin cover an area of 1,409.84 km^2 with an estimated ice reserve of 152.06 km^3. The Gandaki River basin consists of 1,025 glaciers and 338 lakes. The glaciers in the basin cover an area of 2,030.15 km^2 with an estimated ice reserve of 191.39 km^3. The Karnali River basin consists of 1,361 glaciers and 907 lakes, with glaciers covering an area of 1,740.22 km^2 and an estimated ice reserve of 127.72 km^3. Only 35 percent of the Mahakali River basin lies within the territory of Nepal, comprising 87 glaciers and 16 lakes. The area covered by these glaciers is 143.23 km^2 with an estimated ice reserve of 10.06 km^3.

Arial distribution of perennial ice and snow cover in the Indian Himalayan region within GBM basin as described in the overview report "Himalayan Glaciers and River Project" initiated by WWF Nepal Program, WWF India and WWF China Program published in 2005.

In the whole of the Himalayan Range, there are 18,065 glaciers with a total area of 34,659.62 km^2 and a total ice volume of 3,734.4796 km^3 (Qin Dahe 1999). This includes 6,475 glaciers with a total area of 8,412 km^2, and a total ice volume of 709 km^3 in China.

Data Procurement

Fragmentation of information and restrictions on the free use of information has posed serious problems for generalizing hydrological processes in the region and the lack of a long-term historical database on hydrometeorology has been a major scientific constraint. As a consequence, this study was conducted based on secondary data available in different electronic medias, primarily web sites.

Topography Data

River alignments available at IWM had been updated using available physical maps of India, Nepal and Tibet.

GTOPO30, developed in 1996, is a global digital elevation model (DEM) resulting from a collaborative effort led by the staff at the U.S. Geological Survey's. GTOPO30 data set covers the full extent of latitude from 90 degrees south to 90 degrees north, and the full extent of longitude from 180 degrees west to 180 degrees east. The horizontal grid spacing is 30-arc seconds (0.008333333333333 degrees, close to 1 km in GBM Basin). The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate the most complete high-resolution digital topographic database of Earth. Virtually all of the land surface between +/- 60 degrees latitude was mapped by SRTM. The horizontal grid spacing is 3-arc seconds (close to 90 m in GBM Basin).

The SRTM (Version 3) and GTOPO30 data sets had been downloaded and processed having extent covering the entire GBM basin area.

Meteorology Data

Meteorological data essential for this study include: rainfall recorded daily or less time interval, evaporation and temperature. No suitable ground measured rainfall data could be procured for carrying out the study. Daily ground measured rainfall at few stations within GBM basin area seemed to be available in a web site from mid of 2004 and later only. Daily Rainfall data published in web site of Indian Meteorological Department (IMD) was found to be archived at IWM for (June to Sep 2005, and June to Aug 2007). Status of ground measured rainfall was used in the study.

Besides the ground measured rainfall data, Satellite measured rainfall data ($0.25^0 \times 0.25^0$ horizontal resolution) measured by Tropical Rainfall Measurement Mission (TRMM) was downloaded from website for 2004 and later. Satellite measured rainfall data used in CFAN project (($0.5^0 \times 0.5^0$ horizontal resolution) provided by Gatech was also used in the study.

No ground measured evaporation data in the basin area was available except for few stations of Bangladesh. Mean Monthly estimated pan evaporation computed using Christiansen method at different stations in Uttar Pradesh (India) by Water Management Division, New Delhi, was taken from text book (Applied Hydrology by K. N. Mutreja).

Mean monthly temperature data was available at several stations within the basin in websites and procured.

Hydrology Data

Average hydrology data like monthly or yearly average discharge data was available at several stations on the Ganges and Brahmaputra River. No instantaneous hydrology data recorded in India, Nepal, Bhutan or Tibet was available. Historical water levels and discharges at the three outlets of the GBM basin (Hardinge Bridge on the Ganges, Bahadurabad on the Brahmaputra, and Amalshid on the Meghna river) are available. It is to be noted that water levels and discharges at Hardinge Bridge recorded during dry period (January to April) are under control of the Joint River Commission, restricted to use publicly, and thus not available to us. However, Average 10-day discharges both pre Farakka (1935 to 1975) and post Farakka barrage (1975 to 1995) were procured from a publication "The Ganges Water Conflict" By Muhammad Mizanur Rahaman.

Development of Base Model

GBM Basin model in MIKE BASIN platform was developed in 2006 at Flood Forecasting and Warning Centre (FFWC) of Bangladesh Water Development Board (BWDB). The performance of that model was not appreciated since it was developed with limited data and information. More data and information of the basin were available in different organizations and publications, which offered further scope of development.

Tracing of Rivers

All Tributaries of the Ganges and Brahmaputra rivers were traced using tool of MIKE BASIN. The traced river alignments were somewhat different from that procured from different maps and GIS data sets. However, this difference did not entertain any discrepancy in the simulation of model.

Delineation of Sub Catchments

Sub catchments of the GBM basin were re-delineated using version 3 Digital Elevation Model (DEM) developed by USGS based on SRTM data. The new DEM (3 Arc-second grid) was more representative than previous GTOPO30 DEM (30 Arc-second grid). Sub Catchments were delineated considering variability of topography, hydrometeorology and land use pattern in the basin area. The GBM basin model comprises 95 sub catchments out of which 33 were in Brahmaputra basin, 55 were in Ganges basin and the rest 7 were in Meghna basin.

Model Boundaries

Rainfall and evaporation are requisite boundaries for rain fed sub catchments. Rain fed catchments subjected to irrigation require irrigation records which were ignored in this study. Temperature data were incorporated as additional boundary for snow fed catchments.

Simulation of Base Model

Base model was simulated for three rainfall data sets: TRMM satellite rainfall, Gatech rainfall was used in CFAN project, and mixed rainfall data were obtained through processing of ground measured rainfall filling missing period or location with TRMM rainfall. Model simulation was continued from 2004 to 2007.

Calibration & Validation of Model

The GBM Basin model has been calibrated using round the year hydrological feature of 2005. The model has been validated for two subsequent years (2006 and 2007). Sample plots of calibration and validation have been shown in the Figure 2.1.

Simulated runoff of the Ganges basin was compared with measured discharges at Hardinge Bridge on the Padma river. It is observed that simulated runoff could not closely follow the measured discharge, rather there is disagreement in phase and magnitudes. Simulated discharge follows the trend of rated discharge for bulk of the simulation period. During July to September period, simulated monthly flow volume differs from actual by ranging from (-) 8 % to (+) 20 %. It is anticipated that consistent rainfall and evaporation inputs would improve the performance of model.

Measured discharges at Bahadurabad on the Brahmaputra river were compared against simulated runoff of the Brahmaputra basin. Simulated flow was found in satisfactory agreement with the observed data.

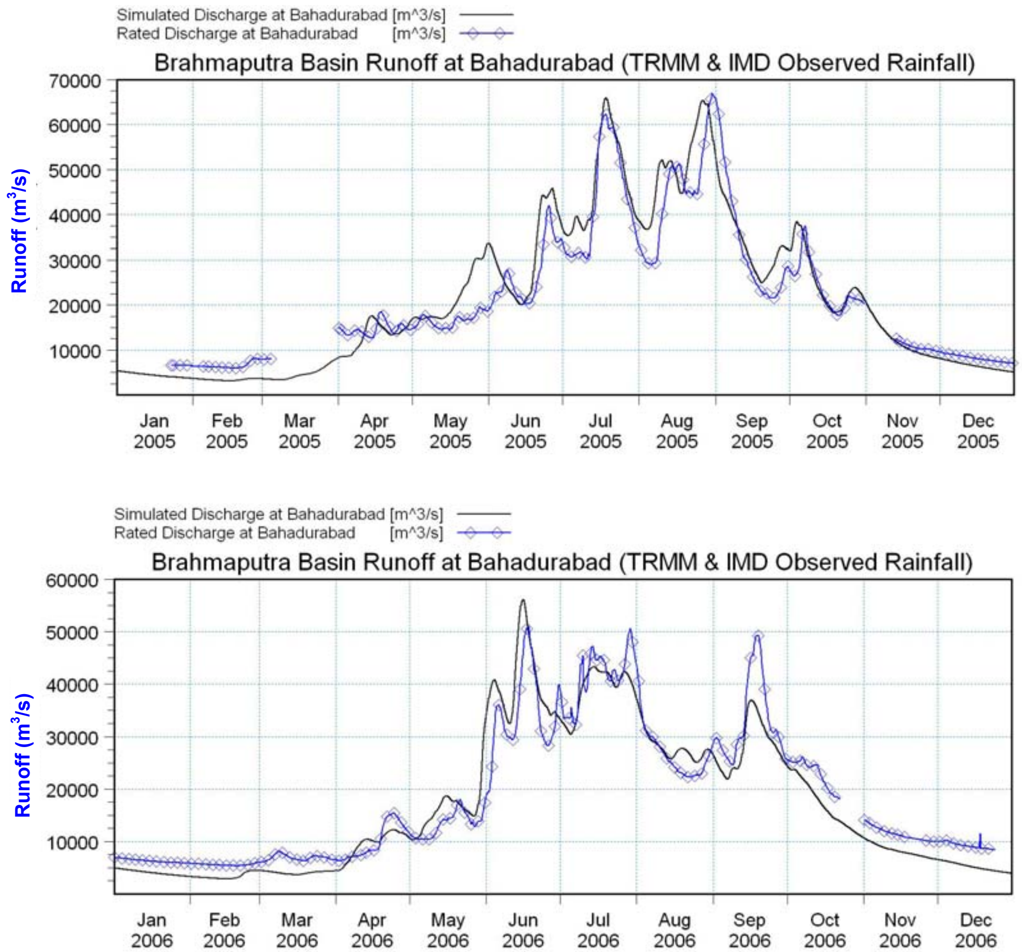

Figure 2.1: Simulated and Observed flow of the Brahmaputra Basin at Bahadurabad

2.2.2 Bay of Bengal Model

The software used for the development of the mathematical model of Bay of Bengal is MIKE21 FM module of DHI Water and Environment. The MIKE 21 FM model system is based on an unstructured flexible mesh consisting of linear triangular elements.

Hydrodynamic Model

The numerical hydrodynamic model is founded on a combination of specific regional information (data) and a generic numerical modelling system MIKE 21 FM. A 2D depth integrated numerical model of the Meghna Estuary and Bay of Bengal have been applied.

The coverage of the model area starts from Chandpur on Lower Meghna river to 16^0 Latitude in the Bay of Bengal. The model applies PWD datum, i.e. level 0.46m is MSL. The grid or mesh size decreases (or the resolution increases) towards coastlines and islands. Inter-tidal areas are flooded and dried during a tidal cycle, both in nature and in the model.

Two open boundaries are identified in the model, one in the north in the Lower Meghna River at Chandpur and one in the south in the Southern Bay of Bengal. The Bay of Bengal is quite deep and the maximum depth along the southern open boundary is more than 2000m.

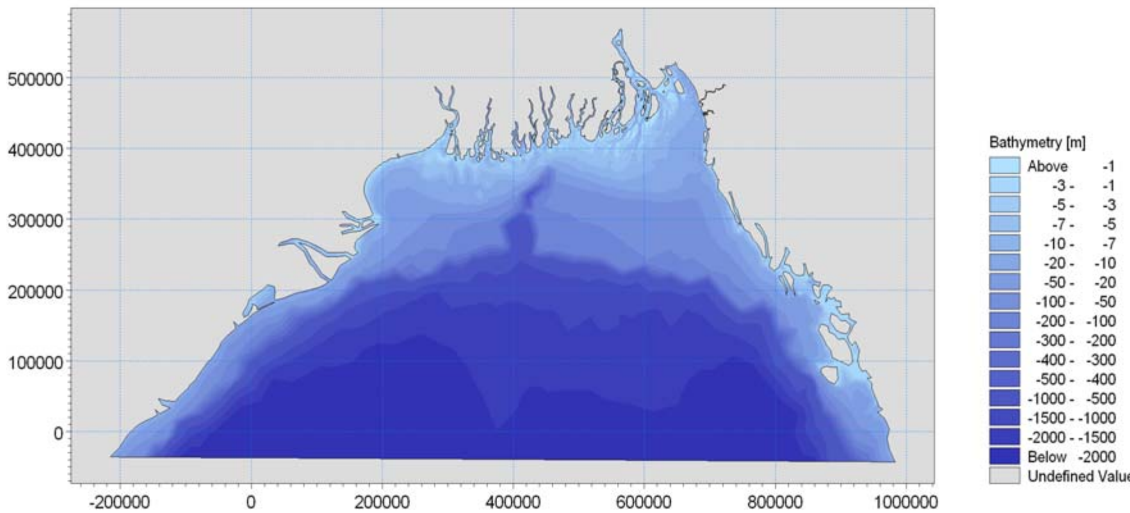

Figure 2.2: Bay of Bengal and Meghna Estuary area covered in the model; color shows the sea bed level in mPWD; dark to light blue represents deep to shallow area.

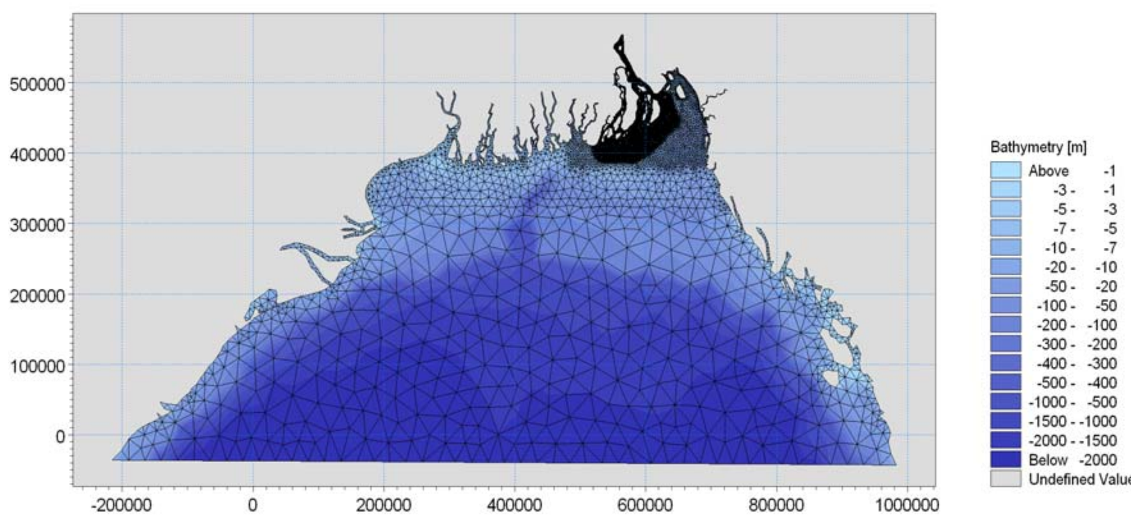

Figure 2.3: Modelled area showing bathymetry and flexible triangular mesh.

The hydrodynamic model has been calibrated and validated against the measured water level and discharge data. The period is illustrated in Table 2.1. Model shows a satisfactory calibration and validation for both dry and monsoon seasons. A sample plot of calibration and validation is presented in the Figure 2.4 to Figure 2.6**.**

Table 2.1: Calibration and validation of the model

	Dry Period	**Monsoon Period**	**Data**
Calibration	February 2006	September 1997	Water level, Discharge
Validation	November 2003		-Do-

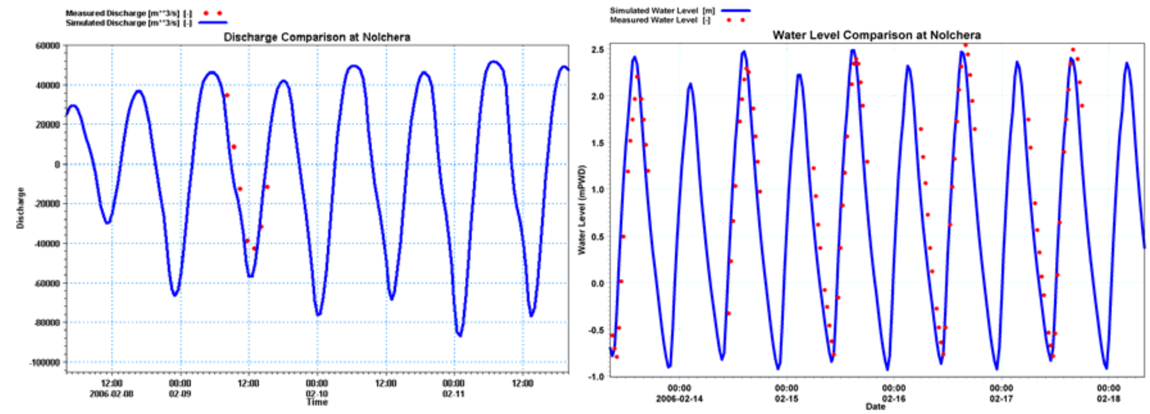

Figure 2.4: Calibration of the Model during dry Period, February 2006; [Left] discharge comparison at North Hatiya, [Right] water level comparison at Charchenga; the model result satisfactorily calibrated against measured data.

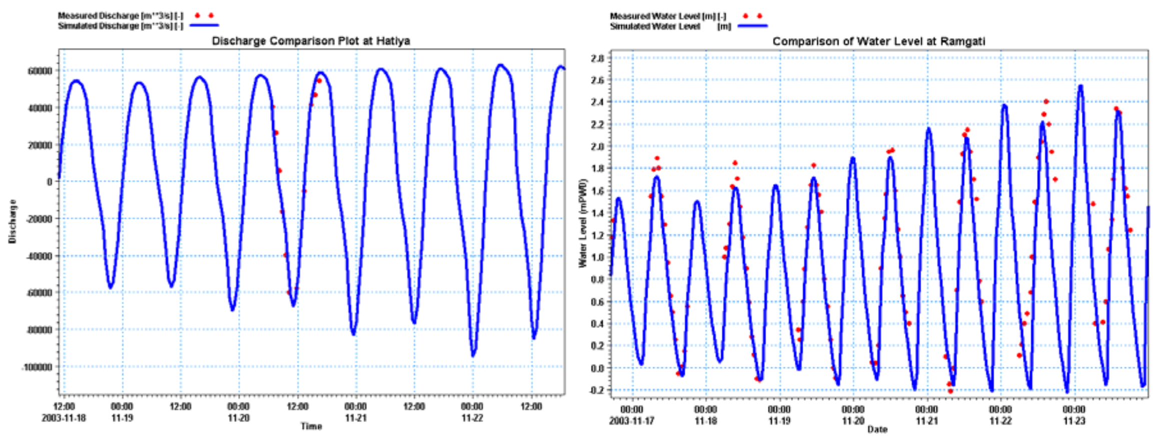

Figure 2.5: Validation of the Model during November 2003; [Left] discharge comparison at North Hatiya, [Right] water level comparison at Ramgati. Model result shows good agreement with the measured data.

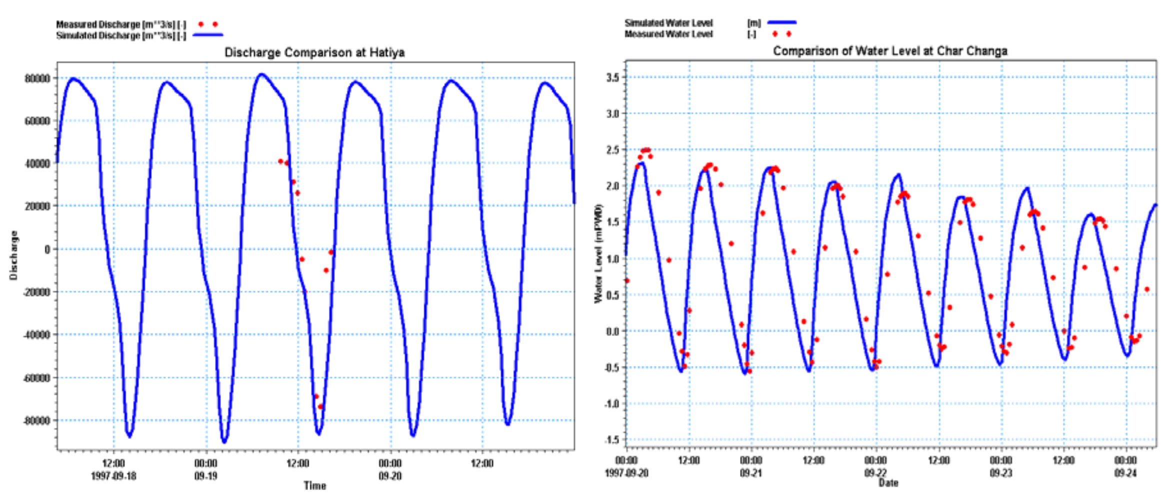

Figure 2.6: Calibration of the Model during monsoon, September 1997; [Left] discharge comparison at North Hatiya, [Right] water level comparison at Charchenga; model show satisfactory calibration in monsoon season.

2.2.3 Regional Models

General Model

The General Model (GM) of Bangladesh was developed at IWM primarily for macro level planning studies on the major rivers and to provide boundary conditions to the regional models. It covers the major river networks of the entire country except the greater Chittagong district and the Chittagong Hill Tracts (Drawing No. 1).

The GM covers an area of approximately 100,000 km^2 inside Bangladesh. The rivers flowing through the model area carry the runoff generated from a catchment more than ten times greater than the land area of Bangladesh.

Major national rivers of Bangladesh, the Jamuna, Ganges, the Padma and the Lower and Upper Meghna, form the backbone of the model. Major regional rivers are the Teesta and the Atrai in the northwest region, the Old Brahmaputra and the Dhaleswari in the north central region and the Surma and the Kushiyara in the north east region.

The GM was the first developed at IWM during Surface Water Simulation Modelling Programme Phase-I (SWSMP-I) (MPO, 1988). It was calibrated for the period April 1980-March 1988. During Phase-II of SWSMP, the model was refined and updated with new cross section data. It was re-calibrated for the hydrological years 1986-87 to 1991-92 and verified with 1992/93 data (SWMC, 1993). During Phase-III of SWSMP, the GM was validated twice. In 1995 the model was validated for the years 1992-93 to 1993-94 (SWMC, 1996). It was further improved by redefining the spill descriptions along the left bank of the Jamuna to bring simulated spill volumes in line with those calculated by the more detailed North Central Region Model (NCRM). The model was validated a second time using 1994-95 hydrological year data (SWMC, 1996). Subsequent validation of the GM covers the following three hydrological years, viz. 1995-96, 1996-97 and 1997-98 (SWMC, 2000).

Using the annual hydrological and recent topographic data, the GM was updated in the last validation for 5 hydrological years: 1998-1999, 1999-2000, 2000-2001, 2001-2002 and 2002-2003. During these validations, the focus was on the improvement of model performance during flood season and the model was updated in light of the recommendations of past validations. The overall performance of the General Model has remained consistently high over the years.

South West Region Model

The South West Region Model (SWRM) covers the entire area lying to the south of the Ganges and west of the Meghna estuary (Drawing No. 3). Total catchment area and length of rivers/channels of the SWRM are around 37,300 km^2 and 5,600 km, respectively. The Bay of Bengal and the international border with India form the southern and western boundaries, respectively. The rivers of the southwest region of Bangladesh are dominated by the tide. Many rivers, particularly those in the southern part, carry very little fresh water flow, but instead act as tidal channels for tides originating in the Bay of Bengal. Freshwater inflows originate from the Gorai, an offtake of the Ganges, and from numerous smaller offtakes from the Lower Meghna.

In the northern part of the model, the main non-tidal river systems comprise the Gorai, Arial Khan, Jayanti and Upper Meghna and Lower Meghna. The southern rivers mainly comprise tidal estuary systems, the largest being the Jamuna, Malancha, Pussur-Sibsa, Baleswar, Tentulia and Lohalia. Interconnected with these larger rivers are a myriad of smaller tidal channels and drainage canals. The tidal channel network is particularly complex in the Sundarbans Mangrove Forest in the far south west corner of the region.

Development of the SWRM was initiated in December 1989 and the data collection started in April 1990. The present model was created towards the end of SWSMP-II, when two smaller sub-regional models covering the South Central and far South West regions were merged to a single model (SWMC, 1993). The Mathabhanga sub-model, which is not hydraulically connected to the main south west region has been modelled separately.

During Phase-III of SWSMP, the SWRM was extended to cover the Sundarbans Mangrove Forest area as a result of a model study carried out for FAO/UNDP (SWMC, 1995). Cross Sections in the morphologically active polder areas west of Khulna were updated with the surveys carried out by IWM. The SWRM was then validated for three consecutive hydrological years, viz. 1995-96, 1996-97 and 1997-98 (SWMC, 2000).

Under the last validation, the SERM was validated for five consecutive years: 1998-1999, 1999-2000, 2000-2001, 2001-2002 and 2002-2003. During these validations, the river systems inside the Sundarban area were updated and a large number of new rivers were incorporated in the model as well. Generated discharges from rating curves were used at some important upstream river boundaries where water level data was used earlier due to absence of updated rating equation. Moreover, some synthesized tidal boundaries were replaced by measured tidal water level data. A consistent performance of the model was observed during these developments of SWRM.

North West Region Model

The north west region of Bangladesh is bounded by the Brahmaputra River to the east, the Ganges to the south, and the international border to the north and west (Drawing No. 4). The North West Region Model (NWRM) covers a catchment area of around 32,600 km^2 and includes over 2,800 km of rivers. An extensive area of depressions or beels exists in the south central part of the region. This area is collectively called as 'Chalan Beel'. In the monsoon the area acts as a huge flood retention reservoir. The main sources of inflow into the region are runoff from local rainfall, which can be very intense, and spilling from the large bordering rivers, particularly the Jamuna and Teesta.

The Karatoya-Atrai-Baral and the Jamuneswari-Karatoya-Bangali are the two main systems draining the greater part of the north west region. The total area drained by these two systems is around 18,000 km^2, i.e. 55% of the total area. The common outlet for these two systems is the Hurasagar River, which joins the Jamuna 15 km north of the Nagarbari Ghat. Other river systems in the region are the Teesta, Dudhkumar, Dharla and the Tangon-Punarbhaba-Mohananda. Small areas, north of Panchagar and west of the Tangon basin, have not been modelled due to the difficulty in obtaining boundary discharge data of the minor border rivers.

The development of NWRM commenced from the inception of SWSMP-II in 1990. During SWSMP-II, NWRM was calibrated and verified with data from 1990 to 1992 (SWMC, 1993). During Phase-III of SWSMP, the model was validated twice, for 1993-94 and 1994-95 hydrological years (SWMC, 1996). Subsequently, NWRM was validated for the following three hydrological years, viz. 1995-96, 1996-97 and 1997-98 (SWMC, 2000). Under the last validation project, NWRM was further validated for five consecutive years: 1998-1999, 1999-2000, 2000-2001, 2001-2002 and 2002-2003. During these validation and model updating, recent river cross-sections were incorporated, Ganges and Mohananda rivers were extended up to international boundary and some improvements were achieved in the schematization of Dudkumar, Atrai and Bangali rivers.

North East Region Model

The North East Region Model (NERM) covers the entire northeastern part of the country, which lies to east of the Old Brahmaputra and north of the Upper Meghna rivers (Drawing No. 6). The NERM covers an area of more than 23,300 km^2, and total length of rivers/channels is around 2,550 km. The region is bordered by the Shillong Hills and the Meghalaya Plateau to the north, the Susang Hills in the northwest and the Tripura Hills in the southeast. Rainfall in the Indian hills is rapidly concentrated forming flash floods in the mountain streams, which sweep into Bangladesh, spilling on to the flat lands as they enter into the country. The central part of the region constitutes the Sylhet Depression, the haors, which becomes deeply flooded during the monsoon by backwater from the Meghna.

The main source of inflow to the region is from the Barak River, which enters Bangladesh at Amalshid in Sylhet. At the border, the Barak bifurcates to form the Surma and Kushiyara rivers, the two main rivers of the eastern part of the region. These two rivers receive most of the flashy river flows, which enter the region from the Meghalaya Plateau and Tripura Hills. The largest of these flashy rivers includes the Sarigowain, Lubhachara, Manu, Khowai and Sonaibardal. Inflows from these tributaries cause considerable spilling from the Surma and Kushiyara during the monsoon. Spill flows follow a wide flood plain on the Kushiyara right bank, eventually joining the Kalni and Dhaleswari rivers before reaching the Upper Meghna.

In the west of the region, the Kangsha, Someswari and Mogra rivers drain a large part of the area. These rivers join the Dhanu and Baulai rivers, which in turn capture additional flash flood flows emerging from the hilly catchments across the border before entering the central depression. The floodplain that constitutes the depression (the haors) carries enormous volumes of water under minimal hydraulic gradient. In the monsoon, the longitudinal gradient in the depression is almost horizontal, falling less than 1 cm per km, but conveying flows of more than 5000 m^3/s. The entire region drains through a single outlet at Bhairab Bazar on the Upper Meghna.

Work on the NERM commenced in January 1991 during SWSMP-II. As very few river cross section data existed in the region prior to 1991, dedicated cross section surveys were carried out in the dry seasons of 1990/91 and 1991/92. The hydrometric network was also considerably expanded to extend the coverage to the smaller rivers and khals, and to include more of the central depression. During SWSMP-II, the model was calibrated and verified with data from April 1991 to July 1993 (SWMC, 1993). During Phase-III of SWSMP, the model was validated for 1993-94 and 1994-95 hydrological years (SWMC, 1996). Afterwards, the NERM went through the process of validation for the three hydrological years, viz. 1995-96, 1996-97 and 1997-98 (SWMC, 2000). Latest validations of this region were carried out under the last validation project for the 1998-1999, 1999-2000, 2000-2001, 2001-2002 and 2002-2003 hydrological years. During the validation process, some rainfall-runoff catchments were redefined based on the latest GIS information and some cross-border catchment runoffs were calibrated using field measurements. Generated cross-border catchment runoff was used at some model boundary instead of generated data. Some link channel parameters were modified for better representation of the actual field condition. Updating of the project features and cross-sections were regular activities during these validations. The model demonstrated consistent performance during these validations.

3. CHANGE OF FREQUENCY OF CHRACTERISTICS FLOOD

Bangladesh is located at the confluence of three large rivers- Ganges, Brahmaputra and Meghna. About 92.5 per cent of the combined basin area of these three rivers lies outside the country. Ganges and Brhmaputra basins are much bigger than Meghna basin. Flooding in Bangladesh highly depends on the magnitude of flow that comes from these two rivers. Frequency analysis of historical discharge data of Brahmaputra River at Bahadurabad has been conducted to examine the increase in number of occurrence of characteristics flood over the past years.

Historic peak flow record of Bahadurabad divided in three equal length series

Time series water flow of Jamuna river at Bahadurabad is available from 1956 to 2007. All the available data have been divided into three parts 1956-73, 1974-1990 and 1991-2007 to carry out statistical analysis to investigate the increase in number occurrence of a specific flood event. Frequency analysis has been done for each part. From the analysis of first part it has been seen that a flood flow of 76,137 m^3/s has a return period of 25 year which means it may occur 4 times in the next 100 years. In the analysis of second part the same flood flow shows return period of 5 year which means that it may occur 20 times in the next 100 years. From the frequency analysis of third part it has been found that the return period for the above water flow is 3.5 year which means that it may occur 28 times in the next 100 years. This analysis shows number of occurrence of a particular flood has increased over the years, which is shown in the Figure 3.1. This indicates that severe flood may come more frequently in future. However, this needs more analysis of flow and rainfall.

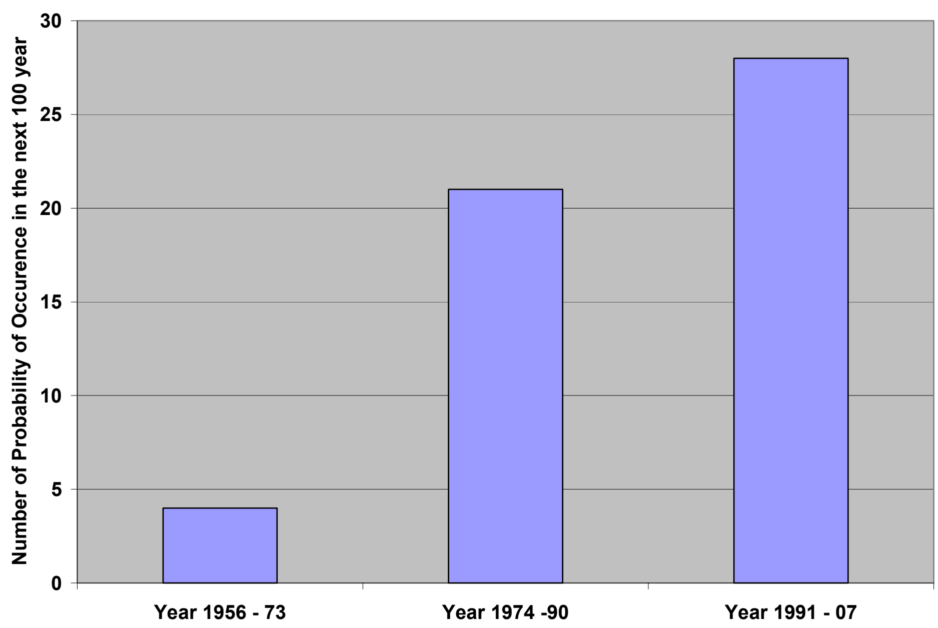

Figure 3.1: Increase in number of occurrence of characteristic flood over the historical years at Bahadurabad.

Historic peak flow record of Bahadurabad divided in two equal length series

Time series water flow of Jamuna river at Bahadurabad has been divided into two parts 1956-1981, 1981-2007 to carry out the same statistical analysis to investigate the increase in number of occurrence of a specific flood event. From the analysis of first part, it has been seen that a flood flow of 81,313 m^3/s has a return period of 25 year which means it may occur 4 times in the next 100 years. In the analysis of second part the same flood flow shows the return period of 5 year which means that it may occur 20 times in the next 100 years. This analysis shows number of occurrence of a particular flood has increased over the years, which is shown in the Figure 3.2.

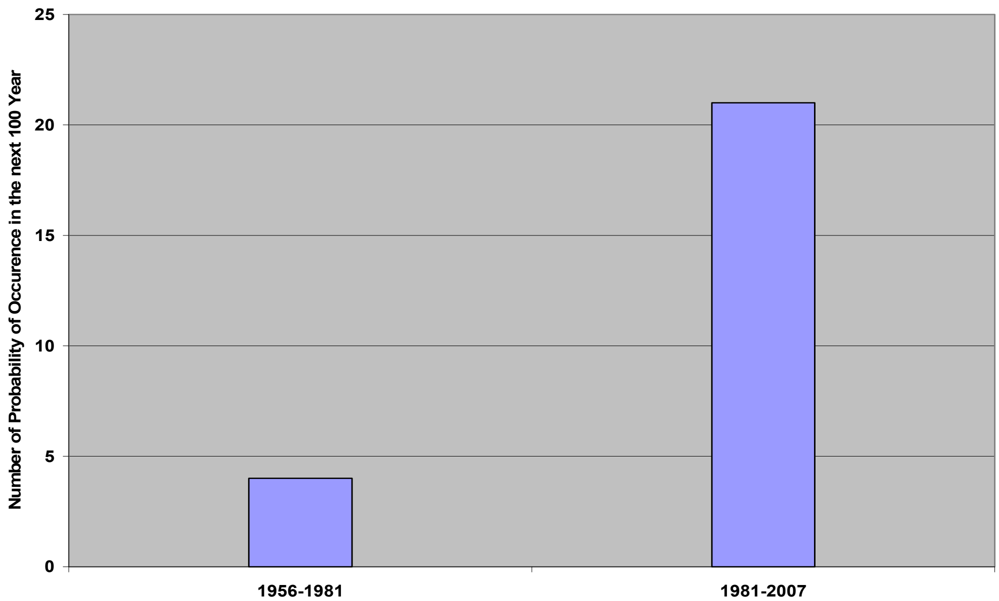

Figure 3.2: Increase in number of occurrence of characteristic flood over the historical years at Bahadurabad.

4. SELECTION OF CLIMATE CHANGE SCENARIO

In the last six years after publication of the IPCC's Third Assessment Report (TAR), significant progress has been made in understanding the past and recent climate change process and in projecting future changes. The key variables affected by climate change and their quantification according to 4^{th} IPCC findings and recent studies are discussed below.

Sea Level Rise

Individual scenarios are considered independent entities in the database. Clearly, in practice, individual scenarios are often related to each other and are not always developed independently. Some are simply variants of others generated for a particular purpose. Many "new" scenarios are designed to track existing benchmark scenarios. A good example is the set of IS92 scenarios, especially the "central" IS92a scenario, which was often used as a reference from which to develop other scenarios.

IPCC (2007) prediction of the global Sea Level Rise (SLR) for IS92a scenario is shown in the Figure 4.1. Using the figure SLR for different year calculated as shown in Table 4.1.

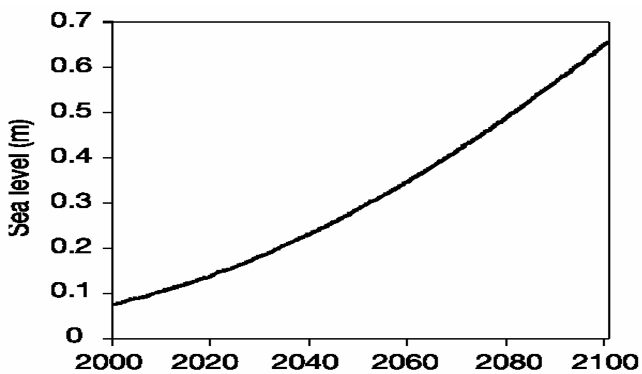

Figure 4.1: Prediction of global sea level rise according to IS92a scenario (AR4).

Table 4.1: Predicted sea level rise for the next 100 years

Year	SLR (cm) above year 2000 level
2020	8
2030	12
2040	17
2050	23
2060	29
2070	36
2080	43
2090	51
2100	59

Precipitation

The Precipitation pattern of Bangladesh cannot be obtained directly from the 4^{th} IPCC report. But precipitation condition of South Asia can be calculated from the report which is presented in the Table 4.2.

Table 4.2: Predicted precipitation change (%) for the next 100 years

Sub-regions	Season	2010 - 2039		2040 - 2069		2070 - 2099	
		A1Fl	B1	A1Fl	B1	A1Fl	B1
South Asia	DJF	-3	4	0	0	-16	-6
	MAM	7	8	26	24	31	20
	JJA	5	7	13	11	26	15
	SON	1	3	8	6	26	10

The precipitation scenarios that have been selected from the Table 4.2 for the present study are shown in the Table 4.3:

Table 4.3: Predicted precipitation change scenarios

Year	2020	2030	2040	2050
Precipitation (%)	7	7	13	13

5. BASELINE CONDITION OF MONSOON FLOODING

Bangladesh is a flood prone country and very often experiences devastating flood during monsoon that causes damage to crops and properties. In normal years, about one fifth of the country is flooded. Climate change poses new threat to change of flood regime that may cause more damage to properties and crops.

It is important to establish baseline condition of flood for assessment of impacts of climate change. There are different approaches to establish baseline condition: it can be considered that last 15-20 years as baseline period that includes different flood events and establish flood inundation and land type on the basis of flood results and then assess the impact of climate change on baseline based on flood results, another approach is to consider average, medium and extreme flood events for establishing baseline condition and then assess the impacts considering that if in future these types (average, medium and extreme) of flood occur impact would be like that. In the present study flood events of 2005 and 2004 are considered to establish baseline/reference condition since statistical analysis shows these floods are average and medium flood event in the Ganges and Brahmmaputra basins. The inundation during monsoon for baseline condition has been assessed through application of calibrated and validated regional flood models for the hydrological year 2005 and 2004. Inundation has been categorized in depth classes as: F0(0-30cm), F1(30-90 cm), F2(90-180 cm), F3(180-360 cm) and F4(>360cm). District wise description of baseline condition has been presented in the following section.

5.1 Selection of hydrological year for average and moderate flood

In order to select the hydrological year for average and moderate flood, frequency analysis method was applied using HYMOS, a hydrological data management and processing tool developed by Delft Hydraulics, the Netherlands. The time series data of annual maximum flow at Baruria on the Padma river and at Bahadurabad on Jamuna river are used for frequency analysis to select hydrological years for average and moderate flood. Maximum annual discharges from 1968 to 2005 at Baruria and from 1956 to 2007 at Bahadurabad have been used for frequency analysis. The magnitude of the moderate flood (10 year return period) and average flood (2.3 year return period) and their coincidence year are shown in Table 5.1. From both the results it has been found that the hydrological year 2005 corresponds to average flood and hydrological year 2004 corresponds to moderate flood. Figure 5.1 shows the results of frequency analysis by Gumbel Distribution of discharge data at Bahadurabad.

Table 5.1: Results of the extreme flow analysis of Padma river at Baruria and Jamuna river at Bahadurabad.

Station	Return Period	Magnitude of flow (m^3/s)		Coincidence flow (m^3/s)	Coincidence year
		Gumbel	Log-Pearson		
Bahadurabad	Moderate (10 year)	83,833	84,195	85,921	2004
	Average (2.3 year)	65,410	65,952	67,059	2005
Baruria	Moderate (10 year)	114,863	114,536	114,127	2004
	Average (2.3 year)	92,283	92,325	98,046	2005

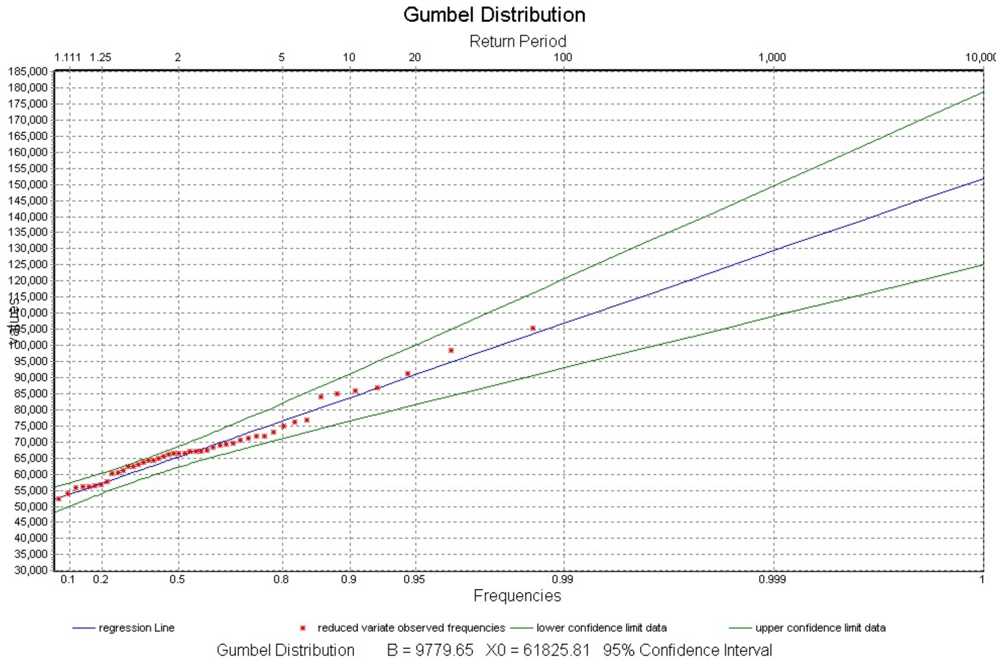

Figure 5.1: Gumbel Distribution of annual maximum discharge data at Bahadurabad.

5.2 Inundation

Gaibandha:

Gaibandha district is situated in the Brahmaputra basin and the total area of this district is 2179.27 square kilometres. It has boundaries with the Kurigram and Rangpur to the north, Bogra District to the south, Dinajpur and Rangpur districts to the west, and Jamalpur and Kurigram districts, and the Brahmaputra River to the east. The district consists of 7 upazilas, 3 municipalities, 18 wards, 82 union parishads, 1101 mouzas, 56 mahallas and 1244 villages. The upazilas are Fulchhari, Gaibandha Sadar, Gobindaganj, Palashbari, Sadullapur, Sughatta and Sundarganj and the municipalities are Gaibandha Sadar, Gobindaganj and Sundarganj. Model results show that 45.85% of Gaibandha district was flooded during peak flood in 2005 i.e. in an average flood event 45.85% of Gaibandha district experiences flood inundation. It is also found that all of its upazilas except Fulchari (7%), Sundarganj (29%) and Gobindaganj (45%) were inundated above 50% during peak flood. In a moderate flood event more area becomes flooded (60 %). The inundated area with depth greater than 30cm and one day duration in an average flood event is illustrated in Table 5.2.

Table 5.2: Inundated area in moderate and average flood events in Gaibandha District

Upazila	Area (km^2)	Area (km^2) corresponding to inundated depth of 0.3m or more	
		Moderate Flood Event (2004 flood)	Average Flood Event (2005 flood)
Fulchhari	306.53	69.9	23.0
Gaibandha Sadar	320.25	226.8	176.5
Gobindaganj	481.66	239.2	218.2
Palashbari	190.67	172.5	148.3
Sadullapur	227.97	187.7	194.0
Sughatta	225.67	162.1	115.4
Sundarganj	426.52	246.5	123.7
Total	**2179.27**	**1304.7**	**999.1**

Sirajganj:

Sirajganj is situated on the right bank of the Jamuna river and one of the flood prone area in Bangladesh. Sirajganj district with an area of 2497.92 sq km, is bounded by Bogra district on the north, Pabna district on the south, Tangail and Jamalpur districts on the east, Pabna, Natore and Bogra districts on the west. The district consists of 4 municipalities, 42 wards, 9 upazilas, 117 mahallas, 79 union parishads, 1467 mouzas and 2006 villages. The upazilas are Belkuchi, Chauhali, Kamarkhanda, Kazipur, Raiganj, Shahjadpur, Sirajganj sadar, Tarash and Ullahpara. In an average flood event about 62% area of the district become flooded and whereas this flooded area increases to 70% in a moderate flood event (2004 flood event). Table 5.3 shows the inundated area.

Table 5.3: Inundated area in moderate and average flood events in Sirajganj District

Upazila	Area (km^2)	Area (km^2) corresponding to inundated depth of 0.3m or more	
		Moderate Flood Event (2004 flood)	Average Flood Event (2005 flood)
Belkuchi	164.31	118.1	91.1
Chauhali	243.67	62.2	59.2
Kamarkhanda	91.61	86.0	80.6
Kazipur	368.63	143.7	122.1
Raiganj	267.83	230.4	187.2
Shahjadpur	324.47	233.2	227
Sirajganj Sadar	325.77	199.2	173.3
Tarash	297.2	279.9	204.9
Ullahpara	414.43	401.9	391.3
Total	**2497.92**	**1754.6**	**1536.7**

Pabna:

Pabna district lies in the Northwest region and bounded by Ganges and Jamuna river and experiences flood very often due to high flood level in the Jamuna and Ganges rivers. The area of the district is 2381.50 sq km. Natore and Sirajganj districts are on the north, Rajbari and Kushtia districts on the south, Manikganj and Sirajganj districts on the east and Kushtia district on the west of Pabna district. It consists of 9 upazilas, 8 municipalities, 81 wards, 72 union parishads, 1321 mouzas and 1540 villages. The upazilas are Atgharia, Bera, Bhangura, Chatmohar, Faridpur, Ishwardi, Santhia, Sujanagar and Pabna Sadar. The municipalities are Bera, Bhangura, Chatmohar, Faridpur, Ishwardi, Santhia, Sujanagar and Pabna Sadar. It is found that 58% of Pabna district was flooded during peak flood in 2005. It is also seen that all of its upazilas except Atgharia (43%), Bera (59%), Chatmohor (72%), Iswardi (7.5%) and Pabna Sadar (22%) were inundated above 90% during peak flood. The baseline inundation of each upazila during peak flood has been shown in Table 5.4.

Table 5.4: Inundated area in moderate and average flood events in Pabna District

Upazila	Area (km^2)	Area (km^2) corresponding to inundated depth of 0.3m or more	
		Moderate Flood Event (2004 flood)	Average Flood Event (2005 flood)
Atgharia	186.15	173.3	81.0
Bera	248.60	146.5	146.5
Bhangura	120.20	111.6	108.7
Chatmohar	314.32	294.5	229.1
Faridpur	145.47	137.2	135.7
Ishwardi	256.90	61.4	19.4
Santhia	331.56	329.8	294.1
Sujanagar	334.40	279.4	275.9
Pabna Sadar	443.90	293.0	96.3
Total	**2381.5**	**1826.7**	**1386.7**

Faridpur:

Faridpur is situated along the Padma river that carries the combined flow of the Jamuna and Ganges rivers. The area of this district is 2103.11 km² and bounded by Rajbari and Manikganj districts on the north, Gopalganj district on the south, Dhaka, Munshiganj and Madaripur districts on the east, Narail, Magura and Rajbari districts on the west. Faridpur district consists of 8 upazilas, 4 municipalities, 79 union parishads, 36 wards, 92 mahallas and 1859 villages. The upazilas are Faridpur Sadar, Boalmari, Alfadanga, Madhukhali, Bhanga, Nagarkanda, Char Bhadrasan and Sadarpur. From model results it is found that 30.5% of Faridpur district was flooded during peak flood in 2005. It is also found that more vulnerable upazilas during peak flood are Sadarpur (72%) and Bhanga (84%). The baseline inundation status of each upazila during peak flood has been shown in Table 5.5.

Table 5.5: Inundated area in moderate and average flood events in Faridpur District

Upazila	Area (km^2)	Area (km^2) corresponding to inundated depth of 0.3m or more	
		Moderate Flood Event (2004 flood)	Average Flood Event (2005 flood)
Faridpur Sadrar	396.00	84.1	30.4
Boalmari	272.34	95.7	7.0
Alfadanga	136.00	39.6	19.0
Madhukhali	230.2	13.1	1.8
Bhanga	216.34	206.1	181.1
Nagarkanda	379.02	229.1	160.7
Char Bhadrasan	183.00	67.0	35.6
Sadarpur	290.21	221.0	207.7
Total	**2103.11**	**955.7**	**643.3**

Sunamganj:

Sunamganj district is situated along the right bank of the Surma river in the Northeast region. The Surma river is characterized by flash flood, flash flood starts from April. Most of the catchment areas lie in India. If it rains heavily in Indian parts of the catchment, the runoff rapidly accumulates and flows to Bangladesh. The duration of flash flood can vary from few minutes to few hours.

The gross area of the district is 3669.58 sq km and bounded by Khasia and Jaintia hills (India) on the north, Habiganj and Kishorganj districts on the south, Sylhet district on the east, Netrokona and greater Mymensingh districts on the west. This district consists of 10 upazilas, 4 municipalities, 36 wards, 82 union parishads, 1711 mouzas and 2813 villages. The upazilas are Bishwamvarpur, Chhatak, Derai, Dharmapasha, Dowarabazar, Jagannathpur, Jamalganj, Tahirpur, Sullah and Sunamganj Sadar. It is found that 74% of Sunamganj district was flooded during peak flood in 2005. It is also found that all of its upazilas except Bishwamvarpur (48%), Chhatak (49%) and Dowarabazar (55%) were inundated above 70% during peak flood. The inundated area in average and moderate flood events is presented in Table 5.6.

Table 5.6: Inundated area in moderate and average flood events in Sunamganj District

Upazila	Area (km^2)	Area (km^2) corresponding to inundated depth of 0.3m or more	
		Moderate Flood Event (2004 flood)	Average Flood Event (2005 flood)
Bishwamvarpur	194.25	122.9	92.7
Chhatak	434.76	410.8	212.0
Derai	420.93	353.0	339.7
Dharmapasha	496.03	451.7	438.9
Dowarabazar	281.40	223.2	155.7
Jagannathpur	368.27	343.9	291.2
Jamalganj	338.74	276.6	273.6
Tahirpur	313.70	245.4	231.3
Sullah	260.74	239.3	238.8
Sunamganj Sadar	560.76	511.2	448.1
Total	**3669.58**	**3178.0**	**2722.0**

Satkhira:

Satkhira lies in the coastal area and characterized by tidal and monsoon flooding. A number of polders were constructed in the sixties and seventies to protect the low lying area from flooding and salinity intrusion. Sea level rise and increased precipitation due to climate change poses increased flooding in the coastal area. This district with an area of 3858.33 km^2, is bounded by Jessore district on the north, the Bay of Bengal on the south, Khulna district on the east, Pargana district of West Bengal on the west. The district consists of 2 municipalities, 18 wards, 7 upazilas, 79 union parishads, 953 mouzas and 1436 villages. The upazilas are Satkhira sadar, Assasuni, Debhata, Kalaroa, Kaliganj, Shyamnagar and Tala and the municipalities are Satkhira Sadar and Kalaroa.

Model results show about 61% of this district get inundated in an average flood. It is also found that all of its upazilas except Assasuni (23%) and Kalaroa (19%) were inundated above 60% during peak flood in 2005. Upzila wise flooded area for baseline condition is shown Table 5.7.

Table 5.7: Inundated area in moderate and average flood events in Satkhira District

Upazila	Area (km^2)	Area (km^2) corresponding to inundated depth of 0.3m or more	
		Moderate Flood Event (2004 flood)	Average Flood Event (2005 flood)
Satkhira Sadar	400.82	-	253.1
Assasuni	402.36	-	93.3
Debhata	176.33	-	147.8
Kalaroa	232.64	-	43.7
Kaliganj	333.79	-	273.5
Shyamnagar	1968.24	-	1308.6
Tala	344.15	-	238.3
Total	**3858.33**	**-**	**2358.3**

Barisal:

Barisal is one of the 19 coastal districts having an area of 2790.51 sq km is bounded by Madaripur, Shariatpur, Chandpur and Lakshmipur districts on the north, Patuakahli, Barguna and Jhalokati districts on the south, Bhola and Lakshmipur districts on the east, Jhalokati, Pirojpur and Gopalganj districts on the west. The district consists of one city corporation, five municipalities, 66 wards, 111 mahallas, 10 upazilas, 86 union parishads, 1147 mouzas and 1175 villages. The upazilas are Agailjhara, Babuganj, Bakerganj, Banaripara, Gournadi, Hizla, Barisal Sadar, Mehendiganj, Muladi, Wazirpur. From model results it is found that 65% of Barisal district was flooded during peak flood in 2005. It is also found that all of its upazilas except Babuganj (45%), Muladi (56%), Hizla (35%) and Gournadi (48%) were inundated above 60% during peak flood. The baseline inundation status of each upazila during peak flood has been shown in Table 5.8.

Table 5.8: Inundated area in moderate and average flood events in Barisal District

Upazila	Area (km^2)	Area (km^2) corresponding to inundated depth of 0.3m or more	
		Moderate Flood Event (2004 flood)	Average Flood Event (2005 flood)
Agailjhara	161.82	162.2	149.1
Babuganj	164.88	127.7	74.0
Bakerganj	417.21	352.6	348.3
Banaripara	134.32	126.2	126.2
Gournadi	144.14	139.4	69.2
Hizla	515.36	182.8	182.3
Barisal Sadar	307.59	229.9	215.6
Mehendiganj	435.79	281.0	280.2
Muladi	261.02	191.9	145.9
Wazipur	248.35	236.5	212.1
Total	**2790.48**	**2030.2**	**1802.9**

5.3 Land Type

Most of the cultivable lands in Bangladesh are subject to annual inundation. The time of flooding, depth, duration of flooding and rate of rise largely determine the choice and timing of crops. Master Plan Organization (MPO) classified the agricultural land resources into five land types on the basis of flood depth and cropping pattern as shown in Table 5.9.

Table 5.9: Classification of land type based on inundation depth (MPO)

Land Type	Description	Flood Depth (cm)	Nature of Flooding	Identifying Crop
F0	Highland	Less than 30	Intermittent	Land suited to HYV rice in the wet season
F1	Medium-high	30-90	Seasonal	Land suited to local varieties of Aus and transplanted Aman
F2	Medium-low	90-180	Seasonal	Land suited to broadcast Aus and broadcast Aman in the wet season
F3	Lowland	Greater than 180	Seasonal	Land on which only broadcast Aman can be grown in the wet season
F4	Low to Very-low	Greater than 180	Seasonal/ Perennial	Land on which either the depth, or rate, or timing, of flooding does not permit growing of broadcast Aman, but does support local Boro in the dry season

Model results were analyzed to find the area under different land type in order to establish the base condition on land type to assess the impact of climate change on land type thereby impact on agriculture. The analysis was made for every upazila since the land type varies largely from one upqazila to another upazila. The depth has been calculated using the national DEM for each upazila and the water level from model results. In the following section the land area under different depth of inundation for every upazila of seven districts is presented and described.

Gaibandha:

Land area of Gaibandha district is presented in different class of land type based on model results for inundation and available DEM as shown in Table 5.10. It is evident that most of the area of Gaibandha district is in the land type of F1 and F2. The main crop during monsoon is transplanted Aman (T aman). The transplanted aman crop is grown in high to medium high land (F0 and F1 land) and broadcast aman is grown in medium low to low land (F2 and F3) where flooding is as high as 180 cm or more. In the Gaibandha district, farmers mainly grow transplanted aman in the cultivable land.

Table 5.10: Upazila wise area under different class of Land type in average flood event (2005 flood) in the Gaibandha district.

Upazila	Area (km^2)	Land Type (km^2)				
		F0	F1	F2	F3	F4
Fulchhari	306.53	0.09	9.90	12.51	0.54	0.00
Gaibandha Sadar	320.25	19.62	92.52	77.13	6.84	0.00
Gobindaganj	481.66	13.59	75.51	111.69	30.96	0.00
Palashbari	190.67	12.24	57.33	67.32	23.31	0.36
Sadullapur	227.97	5.22	56.43	111.51	26.10	0.00
Sughatta	225.67	2.61	46.62	57.33	11.43	0.00
Sundarganj	426.52	21.06	76.50	42.30	4.86	0.00
Total		**74.43**	**414.81**	**479.79**	**104.04**	**0.36**

It is evident that most of the area of Gaibandha district is in the land type of F1 and F2 Land type is changed with the change of flood event. It is seen that F0 and F1 land area has been decreased in a moderate flood. Especially F1 land has decreased significantly eventually F2 and F3 land has increased.

Sirajganj

Land type of different class has been established similarly as it is made for Gaibandha, which is shown in Table 5.11. In this district, more than 66 percent land are within F2 and F3 class in average flood event, which is more than 70% in moderate flood event.

Table 5.11: Upazila wise area under different class of Land type in average flood event (2005 flood) in the Sirajganj district.

Upazila	Area (km^2)	Land Type (km^2)				
		F0	F1	F2	F3	F4
Belkuchi	164.31	9.54	53.19	33.12	4.77	0.00
Chauhali	243.67	1.26	15.03	26.91	16.11	1.17
Kamarkhanda	91.61	2.88	29.16	44.46	7.02	0.00
Kazipur	368.63	9.81	63.72	50.31	8.10	0.00
Raiganj	267.83	5.85	57.69	96.39	32.76	0.36
Shahjadpur	324.47	2.52	25.47	96.3	97.65	7.56
Sirajganj Sadar	325.77	10.26	48.51	83.43	41.40	0.00
Tarash	297.2	10.62	42.48	73.35	87.12	1.98
Ullahpara	414.43	5.49	66.24	194.94	128.97	1.17
Total		**58.23**	**401.49**	**699.21**	**423.9**	**12.24**

Pabna:

The land classification shows that less area is available for transplanted aman cultivation because F0 and F1 land are less compared to F2 and F3. Table 5.12 shows the distribution of land in different class of land type in each upazila for average and moderate flood event.

Table 5.12: Upazila wise area under different class of Land type in average flood event (2005 flood) in the Pabna district.

Upazila	Area (km^2)	Land Type (km^2)				
		F0	F1	F2	F3	F4
Atgharia	186.15	9.18	25.29	23.40	23.67	8.64
Bera	248.60	0.00	10.44	77.94	49.23	8.91
Bhangura	120.20	1.89	11.43	31.50	60.12	5.67
Chatmohar	314.32	11.70	43.20	83.70	91.53	10.71
Faridpur	145.47	0.45	9.63	35.37	75.69	15.03
Ishwardi	256.90	0.09	12.60	6.75	0.09	0.00
Santhia	331.56	13.41	55.44	109.08	117.09	12.51
Sujanagar	334.40	2.43	13.05	80.46	118.89	63.54
Pabna Sadar	443.90	22.41	38.88	38.88	17.37	1.17
Total		**61.56**	**219.96**	**487.08**	**553.68**	**126.18**

Faridpur:

The land in the Faridpur district is more or less well distributed into different class. F1 land is slightly less than F3 and F2 land. Table 5.13 shows the different class of land on the basis of model results and available DEM.

Table 5.13: Upazila wise area under different class of Land type in average flood event (2005 flood) in the Faridpur district

Upazila	Area (km^2)	Land Type (km^2)				
		F0	F1	F2	F3	F4
Faridpur Sadrar	396.00	2.70	15.57	6.66	6.30	1.89
Boalmari	272.34	0.72	3.96	3.06	0.00	0.00
Alfadanga	136.00	4.14	10.26	8.55	0.18	0.00
Madhukhali	230.20	0.18	0.81	0.99	0.00	0.00
Bhanga	216.34	1.80	18.27	76.86	77.49	8.46
Nagarkanda	379.02	6.03	38.07	86.76	35.82	0.00
Char Bhadrasan	183.00	10.53	21.15	13.95	0.54	0.00
Sadarpur	290.21	5.94	48.51	92.97	66.24	0.00
Total		**32.04**	**156.6**	**289.8**	**186.57**	**10.35**

Sunamganj:

The total area of Sunamganj district is higher compared to other 6 districts considered in this study and available land is quite large under F1, F2, F3 and F4 land class. Like other districts F3 land is higher compared to other land type.

Table 5.14: Upazila wise area under different class of Land type in average flood event (2005 flood) in the Sunamganj district

Upazila	Area (km^2)	Land Type (km^2)				
		F0	F1	F2	F3	F4
Bishwamvarpur	194.25	2.52	8.91	17.28	53.55	12.96
Chhatak	434.76	25.20	85.05	99.18	27.72	0.00
Derai	420.93	4.68	25.65	81.54	202.14	30.33
Dharmapasha	496.03	1.26	8.46	53.91	236.70	139.86
Dowarabazar	281.40	11.07	52.56	67.50	34.65	0.99
Jagannathpur	368.27	13.05	74.61	114.30	92.25	10.08
Jamalganj	338.74	0.90	4.95	18.90	117.72	132.03
Tahirpur	313.70	2.34	12.87	19.89	76.41	122.13
Sullah	260.74	0.45	4.14	48.69	170.28	15.66
Sunamganj Sadar	560.76	20.70	94.23	178.29	166.68	8.91
Total		**82.17**	**371.43**	**699.48**	**1178.1**	**472.95**

Satkhira and Barisal

Land area available under different land class of coastal district namely Satkhira and Barisal are shown in the Table 5.15 and Table 5.16.

Table 5.15: Upazila wise area under different class of Land type in average flood event (2005 flood) in the Satkhira district

Upazila	Area (km^2)	Land Type (km^2)				
		F0	F1	F2	F3	F4
Satkhira Sadar	400.82	6.75	43.74	61.56	147.78	0.00
Assasuni	402.36	0.00	0.09	1.98	91.26	0.00
Debhata	176.33	0.90	5.67	41.31	100.80	0.00
Kalaroa	232.64	5.67	17.19	21.96	4.50	0.00
Kaliganj	333.79	0.09	7.20	33.84	232.47	0.00
Shyamnagar	1968.24	0.00	0.09	169.11	1139.31	0.09
Tala	344.15	22.50	47.52	62.55	128.25	0.00
Total		**35.91**	**121.5**	**392.31**	**1844.37**	**0.09**

Table 5.16: Upazila wise area under different class of Land type in average flood event (2005 flood) in the Barisal district

Upazila	Area (km^2)	Land Type (km^2)				
		F0	F1	F2	F3	F4
Agailjhara	161.82	8.10	79.29	68.49	1.35	0.00
Babuganj	164.88	20.70	65.07	8.91	0.00	0.00
Bakerganj	417.21	8.37	266.85	80.82	0.63	0.00
Banaripara	134.32	0.00	16.56	109.08	0.54	0.00
Gournadi	144.14	21.51	56.25	12.96	0.00	0.00
Hizla	515.36	2.52	43.56	76.23	62.46	0.00
Barisal Sadar	307.59	30.33	171.45	40.95	3.24	0.00
Mehendiganj	435.79	2.61	125.46	148.05	6.66	0.00
Muladi	261.02	13.59	68.49	75.69	1.71	0.00
Wazipur	248.35	9.90	82.35	128.25	1.53	0.00
Total		**117.63**	**975.33**	**749.43**	**78.12**	**0.00**

6. IMPACT OF CLIMATE CHANGE ON MOSOON FLOODING AND LAND TYPE

6.1 Impact on Monsoon Flooding

As floods in Bangladesh are caused by intense monsoon precipitation over the basin areas of Ganges, Brahmaputra and Meghna rivers, future increase in precipitation due to climate change will increase monsoon flooding in Bangladesh. Increase of sea level rise along with the increase of precipitation will cause more devastating flood during monsoon. Assessment of change of future flood regime in Bangladesh requires the inflow in the Brahmaputra / Jamuna, Ganges and Meghna rivers since flood in Bangladesh largely depends on rainfall runoff from GBM basin. In the present study inflow in the major rivers are generated using calibrated GBM basin model increasing the precipitation by 13% over the GBM basin and 17 cm sea level rise is considered in accordance with the IPCC prediction to establish flooding pattern in 2040. Impacts on flooding and land type have been assessed comparing the inundated area of different depths in 2040 with those of 2004 and 2005. The impact on flooding has been described for each selected seven districts. The impact has been assessed during peak flood considering 12 hour to one day duration and depth equal to and greater than 30 cm. It has been found that inundated area is increased from 8 to 16 percent for average flood event due to climate change as shown in Table 6.1.

Table 6.1: Impact on monsoon flooding

Upazila	Area (km^2)	Inundated area (>= 0.3m) (km^2)					
		Average Flood 2005	Climate Change Condition	% increase due to CC	Medium Flood 2004	Climate Change Condition	% increase due to CC
Faridpur	2072.72	643.3	723.5	12.47	955.5	1084.6	13.51
Sirajganj	2497.92	1536.8	1709.2	11.21	1754.6	1791.0	2.08
Sunamganj	3669.58	2722.0	2841.0	4.37	3177.9	3204.0	0.82
Sathkhira	3858.33	2358.3	2409.5	2.17			
Barisal	2790.51	1802.9	1946.8	7.98	2030.1	2080.6	2.49
Gaibandha	2179.27	999.0	1129.8	13.09	1304.7	1411.9	8.22
Pabna	2371.5	1386.9	1613.3	16.33	1826.6	1834.0	0.40

Gaibandha, Sirajganj, Pabna and Faridpur districts are likely to be affected significantly as more area gets inundated due to climate change. The flooded area is increased by 22,700 ha in the district of Pabna in an average flood condition due to 13 % increase of precipitation. This increased flooding area may affect more people and property. Increased flooded area is also significant in the Faridpur and Gaibandha districts.

6.2 Impact on Flood Level and Duration

It is seen that the flood level and its duration increases in the Jamuna and Ganges river due to increase of precipitation over the GBM basin. About 37cm increase is seen at peak time in a moderate flood event (2004 flood event) and in a normal flood event (2005 flood event) the increase is about 27cm in the Jamuna river. The duration of flood level (danger level 19.5m, PWD as considered by FFWC) increases from 10 days to 16 days and 3 days duration flood level (20 m, PWD) prolongs to 8 days due to climate change in a moderate flood event in the

Jamuna river. It is also seen that increase of flood level is also very high in a normal flood event in the Ganges river, which is more than 50cm. Statistical analysis of historical time series of annual peak flow shows frequency of moderate flood has increased considerably from early eighties.

Table 6.2: Change of flood level and duration due to climate change (Moderate Flood)

Station	Duration of flood			Maximum Flood level			Maximum Flow		
	Flood Level (mPWD)	Flood Event		Flood Event		Depth increase in 2004	Flood Event		Flow increase in 2004
		2004	2040	2004	2040		2004	2040	
Bahadurabad	19.5 (Danger Level)	10 days	16 days	20.19 mPWD	20.56 mPWD	37 cm	85,921 m^3/s	99,036 m^3/s	13,115 m^3/s
	20	3 days	8 days						
Sirajganj	13.75 (Danger Level)	17 days	19 days	14.81 mPWD	15.17 mPWD	36 cm	86,500 m^3/s	99,800 m^3/s	13,300 m^3/s
	14.5	6 days	10 days						
	14.7	3 days	8 days						
	15	0 days	3 days						

Table 6.3: Change of flood level and duration due to climate change (Average Flood)

Station	Duration of flood			Maximum Flood level			Maximum Flow		
	Flood Level (mPWD)	Flood Event		Flood Event		Depth increase in 2005	Flood Event		Flow increase in 2005
		2005	2040	2005	2040		2005	2040	
Bahadurabad	19.5 (Danger Level)	0 days	5 days	19.34 mPWD	19.61 mPWD	27 cm	67,060 m^3/s	71,064 m^3/s	4,004 m^3/s
	19.28	3 days	14 days						
	19	15 days	26 days						
Hardinge Bridge	14.25 (Danger Level)	0 days	11 days	14.05 mPWD	14.68 mPWD	63 cm	44,278 m^3/s	54,234 m^3/s	9,956 m^3/s
	14	2 days	27 days						
	13.9	4 days	34 days						
	13.5	25 days	54 days						

6.3 Impact of Climate change on Land Type

Assessment of impact on land type will determine the change on agricultural yield since it is associated with cropping pattern. The decrease of F0 and F1 land will decrease the cultivable land for transplanted aman crop similarly increase of these land type will increase the opportunity to cultivate T.aman in more land. Land type has been assessed for each upazila for the seven districts due to climate change using the model results that have been generated increasing the precipitation over the entire catchment on average and moderate flood events. The impacts on each type of land for every district have been calculated as shown in Table 6.4 and is shown in Figure 6.1 to 6.12. Generally F0 and F1 land has decreased in every district except Faridpur, district which implies that land suitability for T aman in Khrif-II season, would decrease over the country due to climate change. In contrast, F3 and F4 land has increased considerably in all districts. In Sirajganj district, the decrease of F0 and F1 is 44% and 42% respectively. The decrease of F0 and F1 land is also quite large in the Barisal district which is 43 % and 32 %, on the other hand the percent increase of F3 and F4 land are quite high, which implies deep inundated area would increase.

Table 6.4: Impact on land type

Districts	Area (km^2)		Land Type (km^2)				
			F0	F1	F2	F3	F4
Faridpur	2072.72	Inundation at 2005	32.04	156.60	289.80	186.57	10.35
		Inundation at 2040	33.66	163.71	308.79	240.66	10.35
		% increase	5.06	4.54	6.55	28.99	0.00
Sirajganj	2497.92	Inundation at 2005	58.23	401.49	699.21	423.90	12.24
		Inundation at 2040	32.13	230.76	694.31	748.71	35.37
		% increase	-44.82	-42.52	-0.70	76.62	300 percent
Sunamganj	3669.58	Inundation at 2005	882.17	371.43	699.48	1178.10	472.95
		Inundation at 2040	65.16	324.54	672.30	1268.46	575.71
		% increase	-20.70	-12.62	-3.89	7.67	21.73
Satkhira	3858.33	Inundation at 2005	35.91	121.50	392.31	1844.37	0.09
		Inundation at 2040	27.72	127.70	216.00	2063.97	0.81
		% increase	-22.81	5.93	-44.94	11.91	Significant
Barisal	2790.51	Inundation at 2005	117.63	975.33	749.43	78.12	0.00
		Inundation at 2040	66.24	658.80	1161.81	126.18	0.00
		% increase	-43.69	-32.45	55.03	61.52	0.00
Gaibandha	2179.27	Inundation at 2005	74.43	414.81	479.79	104.04	0.36
		Inundation at 2040	73.44	333.27	570.87	224.73	0.90
		% increase	-1.33	-19.66	18.94	Significant	Significant
Pabna	2371.50	Inundation at 2005	61.56	219.96	487.08	553.68	126.18
		Inundation at 2040	55.35	198.90	410.94	721.98	281.52
		% increase	-10.09	-9.57	-15.63	30.40	Double

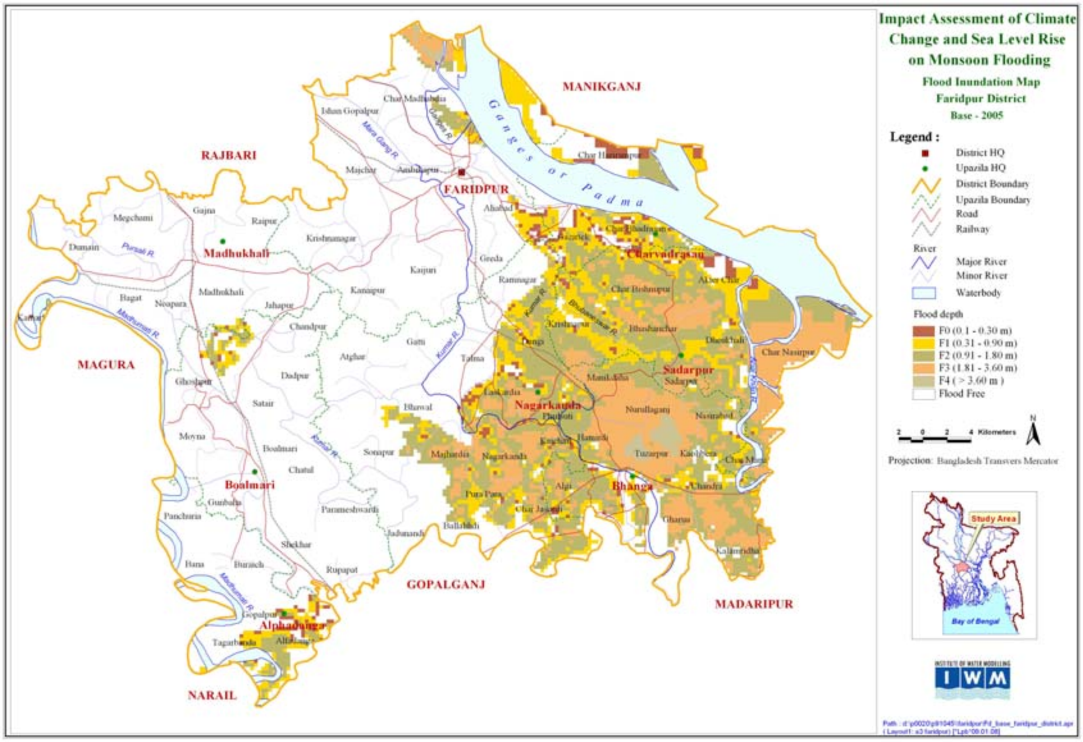

Figure 6.1: Inundated Area Base Condition, Faridpur District (Average Flood, Year 2005)

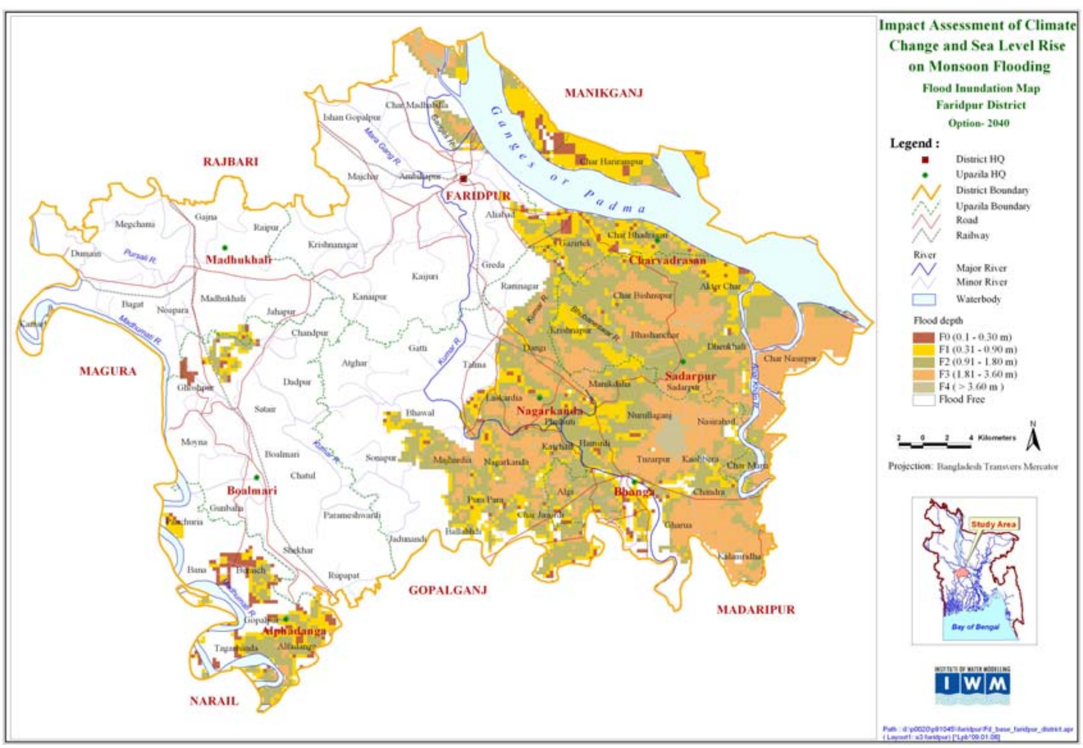

Figure 6.2: Impact on Inundated Area due to Climate Change Condition, Faridpur District (Year 2040)

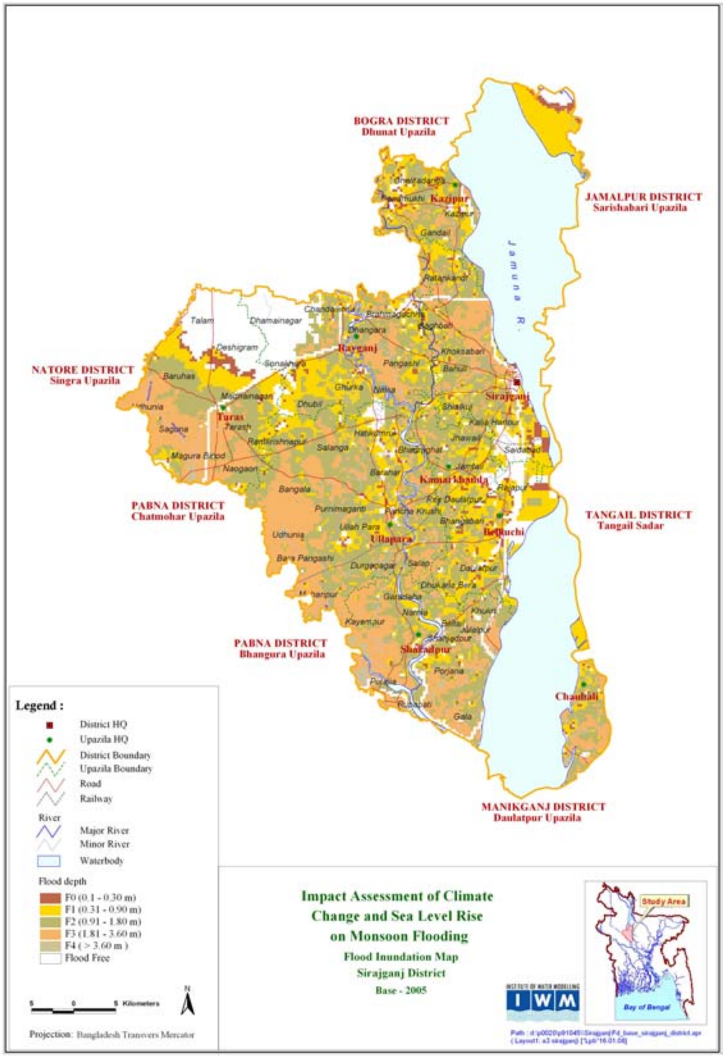

Figure 6.3: Inundated Area Base Condition, Sirajgang District (Average Flood Year, 2005)

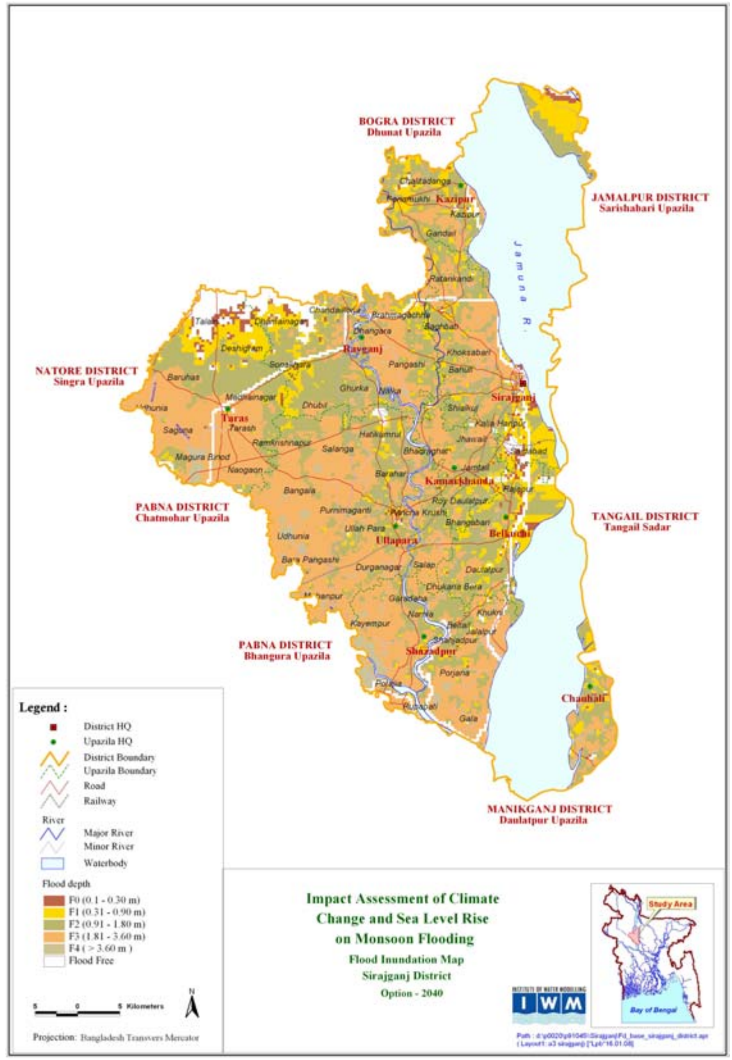

Figure 6.4: Impact on Inundated Area due Climate Change Condition, Sirajgang District (Year 2040)

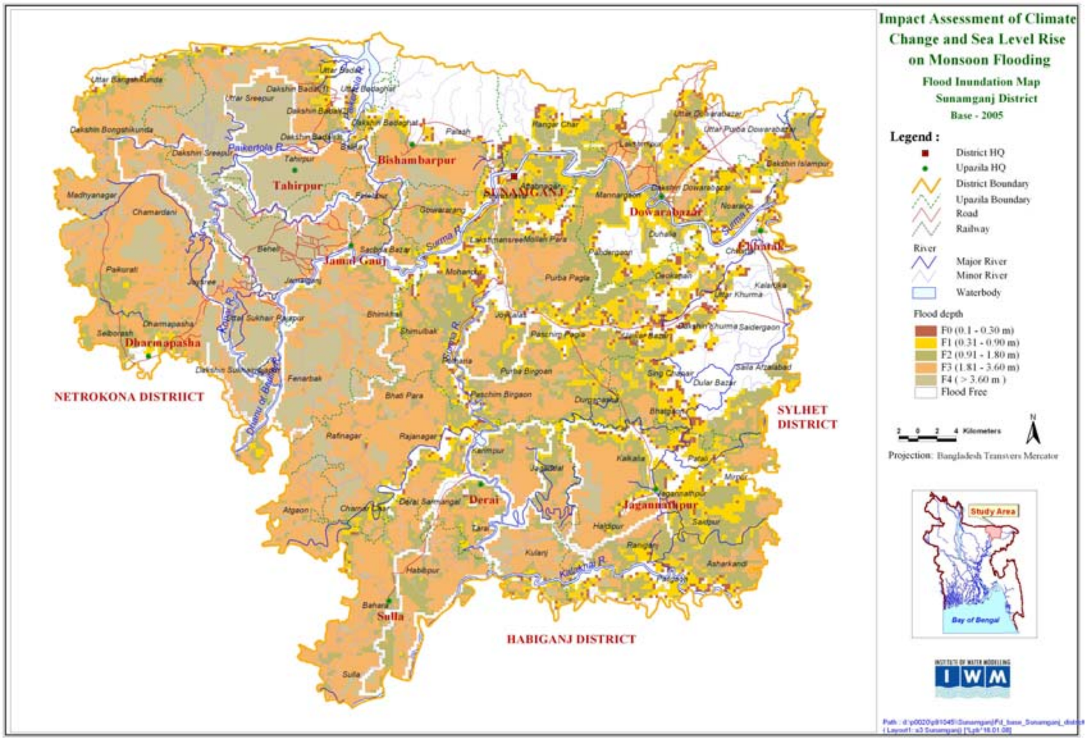

Figure 6.5: Inundated Area Base Condition, Sunamganj District (Average Flood, Year 2005)

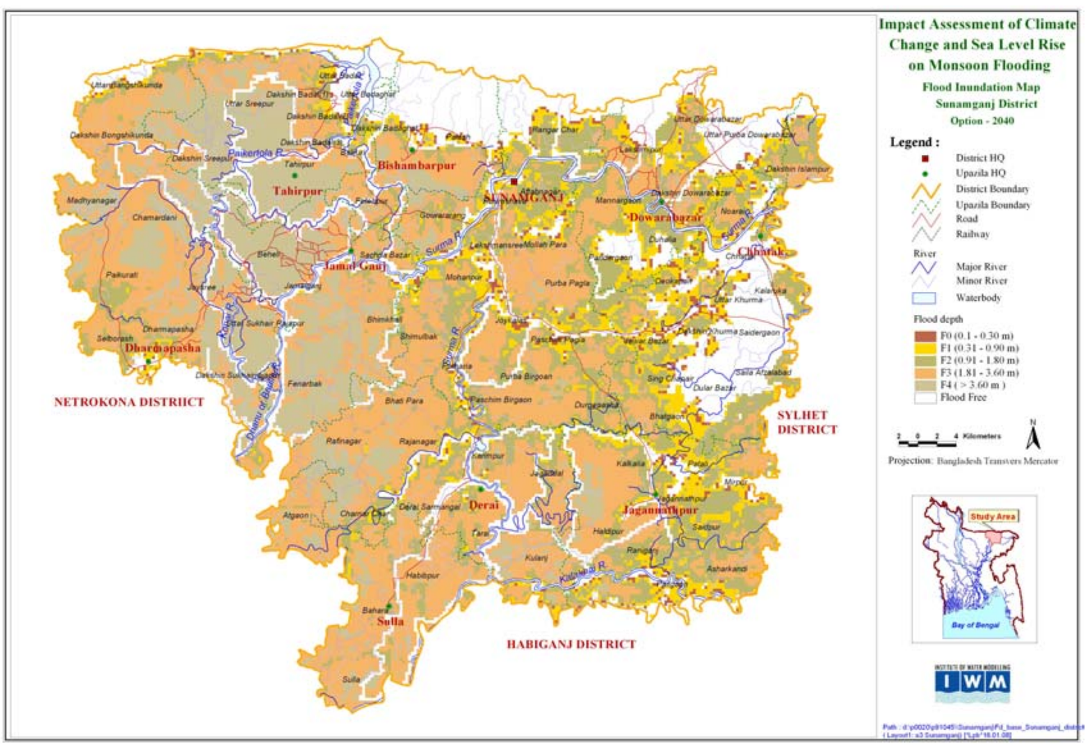

Figure 6.6: Impact on Inundated Area due to Climate Change Condition, Sunamganj District (Year 2040)

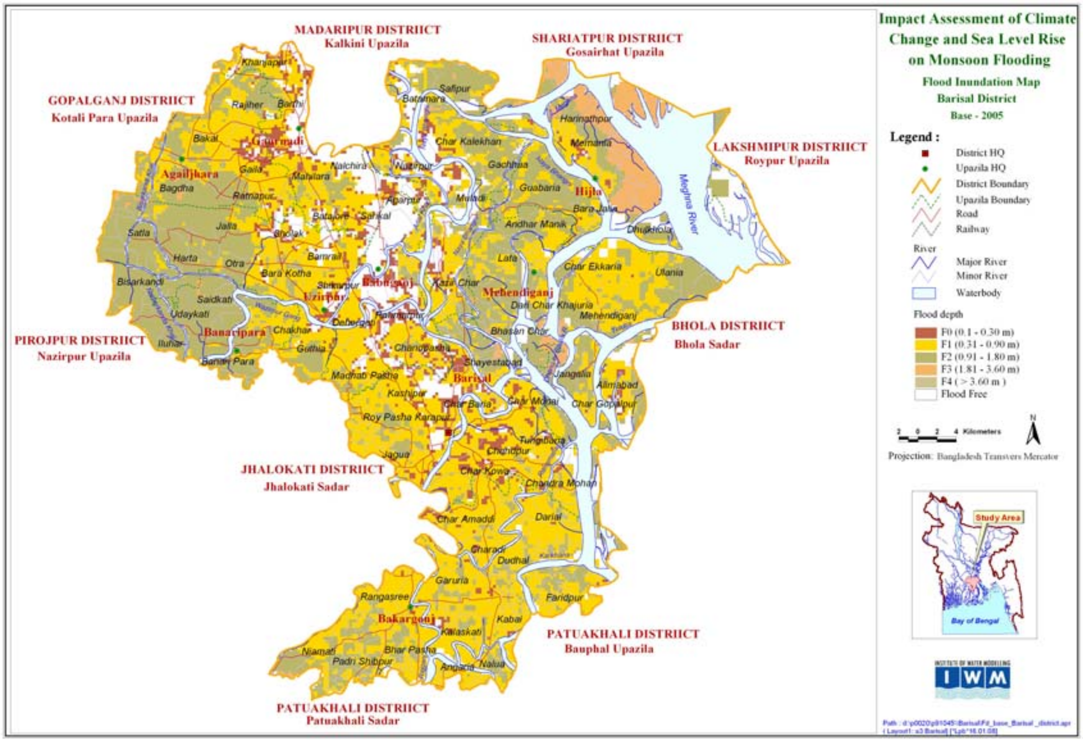

Figure 6.7: Inundated Area Base Condition, Barisal District (Average Flood, Year 2005)

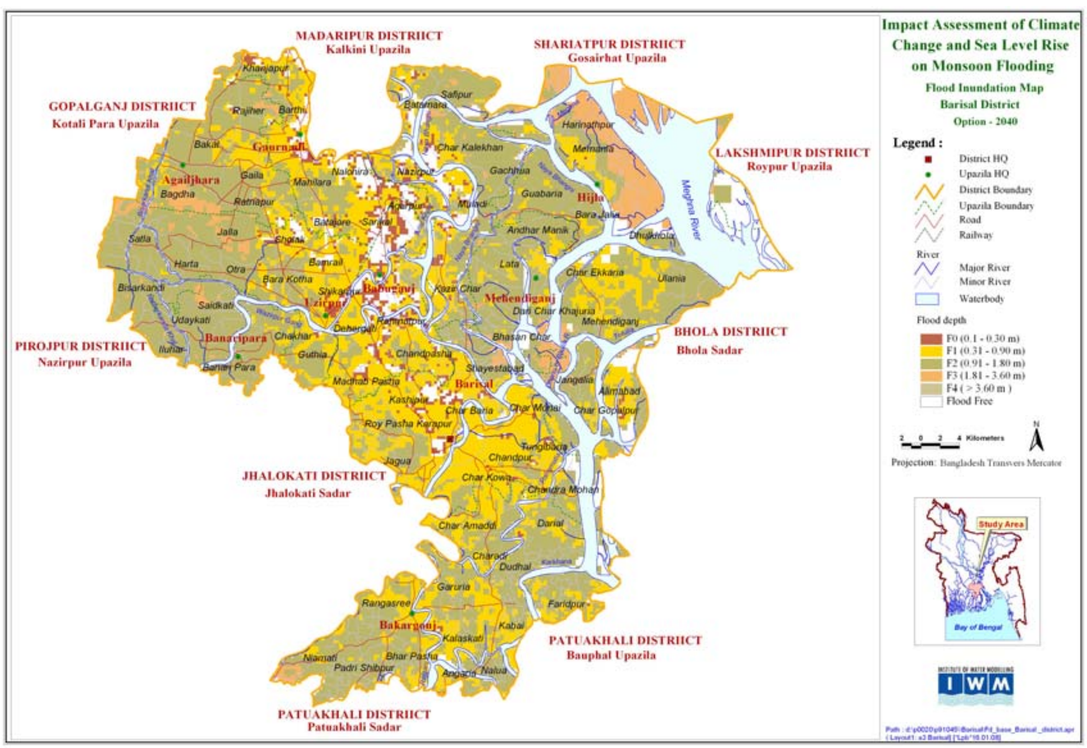

Figure 6.8: Impact on Inundated Area due to Climate Change, Barisal District (Year 2040)

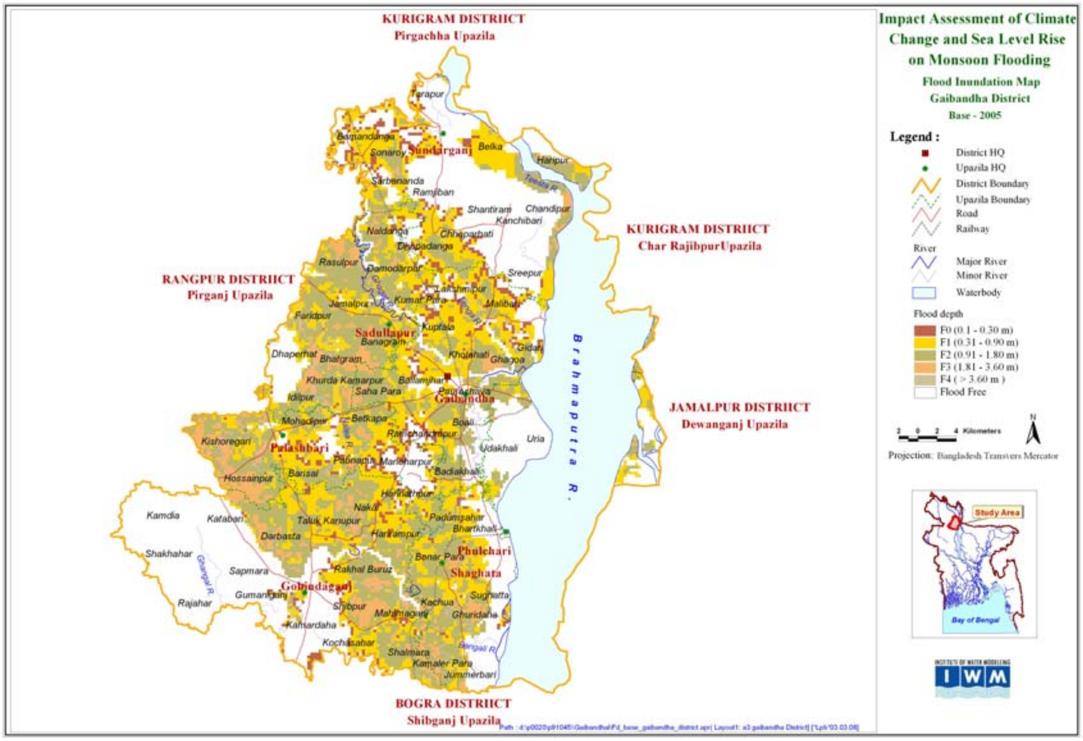

Figure 6.9: Inundated Area Base Condition, Gaibandha (Average Flood, Year 2005)

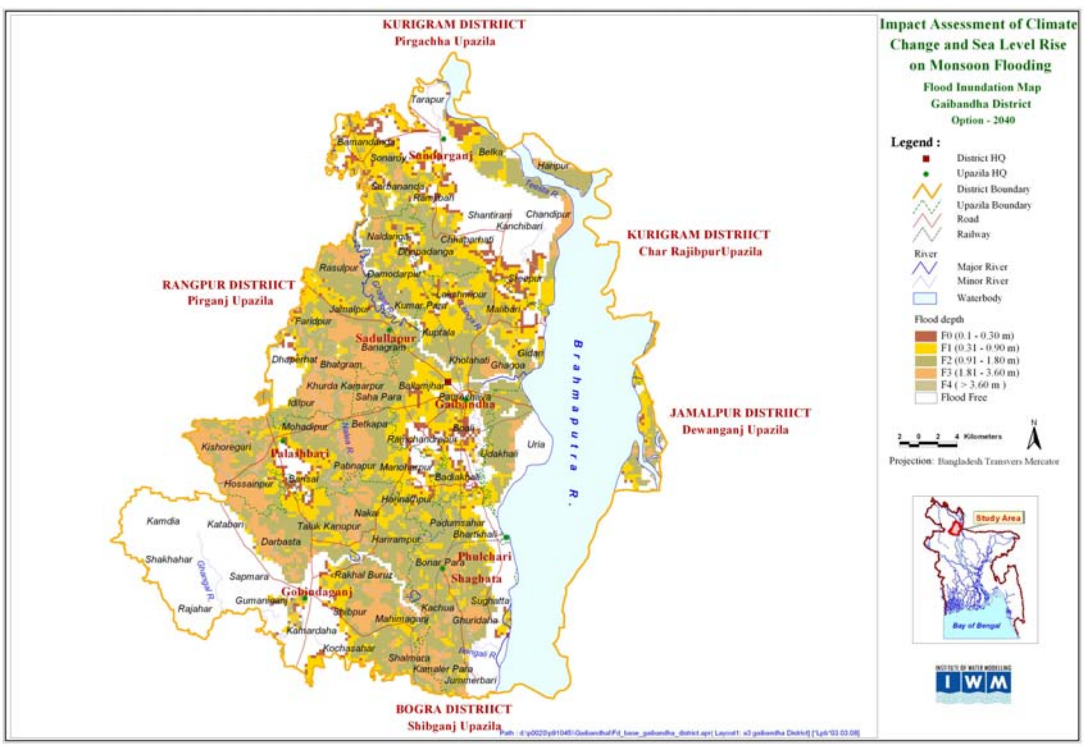

Figure 6.10: Impact on Inundated Area due to Climate Change, Gaibandha (Year 2040)

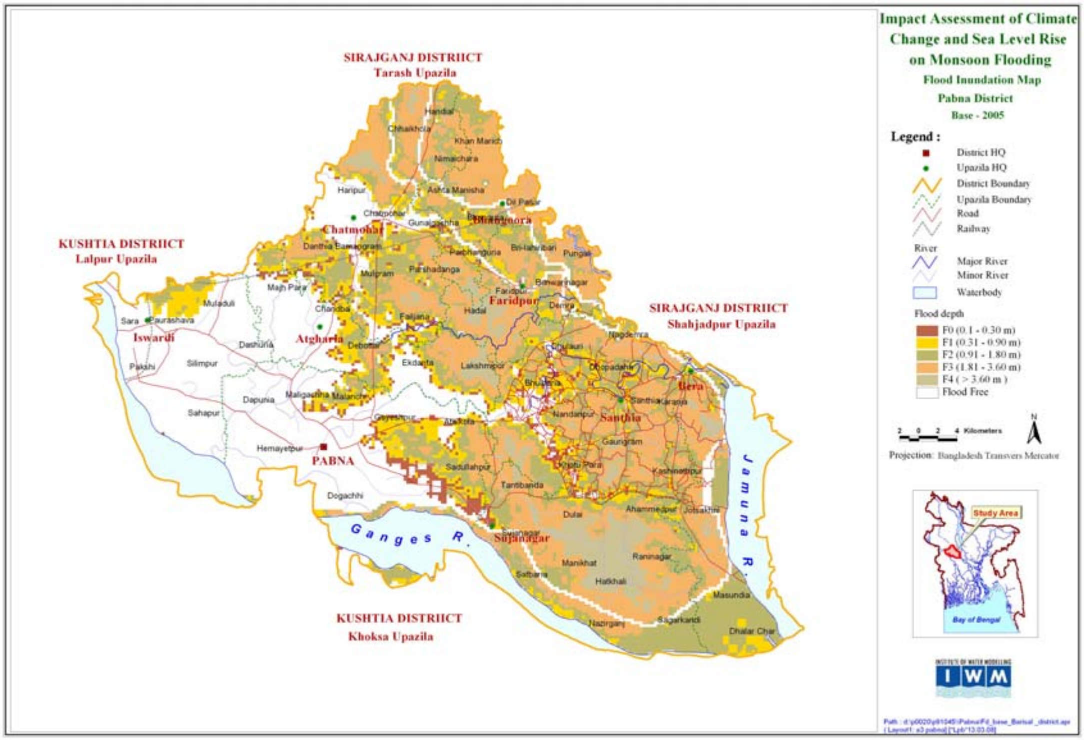

Figure 6.11: Inundated Area Base Condition, Pabna District (Average Flood, Year 2005)

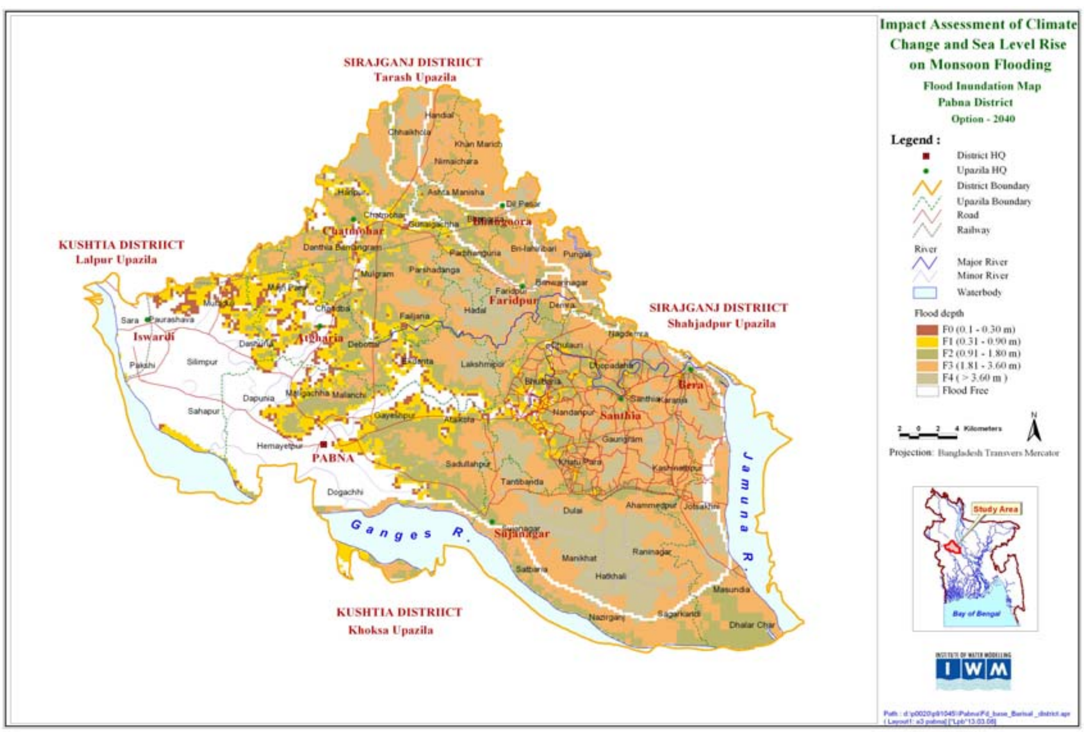

Figure 6.12: Impact on Inundated Area due to Climate Change Condition, Pabna District (Year 2040)

Impact on land type for every upazila of seven districts is summarized in the following section and details of it is presented in tabular form in Annex-A, and in maps in Annex B.

For an example in the Sirajganj district in the year 2040, available F0 and F1 land area are 3,200 ha and 23,000 ha for an average flood event, whereas in a moderate flood event the F0 and F1 land decreased significantly, the F0 and F1 area became 774 ha and 9,300 ha respectively. Table 6.4 shows the available F0 and F1 land in 2040 that has been assessed considering the climate change. It is evident that F0 and F1 land decreased significantly in all seven districts in a moderate flood event compared to normal flood event.

Effects of climate change is investigated on land type over the monsoon period (June to October), it is seen that impact of climate change prevail over the whole Khrf-II period (July-October). The monthly change of land type is presented in Table 6.5 for Sirajganj district. It is apparent from the table that in all the month in this district the F0 and F1 land decreased in contrast F3 and F4 land are increased, which may bring change in present agricultural practice. Impact assessment for other districts is given in Appendix-C.

Table 6.5: Change of land type over the monsoon due to climate change in Sirajganj District

Month	Year	Land Type (km^2)				
		F0	F1	F2	F3	F4
July	2005	56.52	404.73	698.94	415.71	11.61
	2040	34.56	239.49	691.47	741.87	33.93
August	2005	111.87	467.46	476.28	297.45	10.44
	2040	57.33	389.79	664.47	489.96	26.91
September	2005	120.33	461.97	475.56	270.99	8.19
	2040	73.35	422.46	648.45	435.51	21.87
October	2005	69.12	383.22	530.91	210.87	2.79
	2040	49.23	303.30	667.98	433.53	6.66

7. CONCLUSIONS

The potential impacts of climate change in Bangladesh are more floods, more droughts, drainage congestion, salinity intrusion and cyclones with higher intensities. All of which have severe implications on agriculture production and livelihood of people. However, the extent, intensity and magnitude of impacts are not known exactly. Present study mainly focused on assessment of impacts of climate change and sea level rise on monsoon flood and land type since land type will determine the change on agricultural yield as it is associated with cropping pattern. The decrease of F0 and F1 land will decrease the cultivable land for transplanted Aman crop. Under this study the Ganges, Bramahputra and Meghna basin hydrological model has been updated, calibrated and validated from its course condition, which is an achievement of the present study. This GBM basin hydrological model has been applied first time to assess the inflow in the major rivers of Bangladesh for climate change scenario, which is essential to assess the impacts of climate change on flood regime of this country.

It is seen that inundated area is increased by 12 to 16 percent in the Ganges and Jamuna basin for average or normal flood event way due to climate change. Peak flood level increases by about 37cm in a moderate flood event (2004 flood event) and in a normal flood event (2005 flood event) the increase is 27cm in the Jamuna river. In the Ganges river the increase of flood level is also very high in a normal flood event, which is more than 50cm. The duration of flood level (danger level 19.5m, PWD as considered by FFWC) increases from 10 days to 16 days and 3 days duration flood level (20m, PWD) prolongs to 8 days due to climate change in a moderate flood event in the Jamuna river. Statistical analysis of historical time series of annual peak flow shows frequency of moderate flood has increased considerably from early eighties. It is important to investigate the impact of climate change on flood regime of Bangladesh considering different GCM model predictions (low, average and high) or other model predictions (PRECIS) for GBM basin for different emission scenarios. This may provide a range of impacts for low, mean and high precipitation and temperature increases.

F0 and F1 land decreases in every district eventually availability of land for T aman in Khrif-II season would decreases gradually over the country due to climate change. In contrast, F3 and F4 land increases considerably in all districts. The decrease of F0 land is quite large in the Jamuna and Gganes basin, which is in the range of 43 to 44% , the coastal districts also shows similar decrease of F0 land. The decrease of F0 land is about 43% and in case of F1 the decrease is comparatively less. Impact on land type varies over the Kharif-II crop season i.e. from July to October. The availability of land area for T aman becomes extremely less in a moderate flood event compared to normal flood event, in Sirajganj district

It is seen in Sirajganj district in the year 2040, available F0 and F1 land area are 3,200 ha and 23,000 ha for an average flood event, whereas in a moderate flood event the F0 and F1 land decreased significantly, the F0 and F1 area become 774 ha and 9,300 ha respectively. It is evident that moderate flood with increased precipitation would cause severe implication on monsoon crops since availability of F0 and F1 land would be less.

There are limitations in the results because of several assumptions. The increase of precipitation has been assumed 13% over the GBM basin for the whole monsoon period according to 4th IPCC, in reality there will be temporal and spatial variation of the increase of precipitation during monsoon and over the GBM basin in future. Once the results of PRECIS model is available for the GBM basin then the results can be updated and improved.

Climate change and sea level rise will continue to affect Bangladesh through permanent inundation and drainage congestion. This will impact on food security and livelihood significantly. It is also important to revisit the planning and design of existing infrastructure and to rehabilitate these structures to make it climate resilient. The risk of climate change and sea level rise are to be considered for future planning and design of water and environmental projects. Proper adaptation measures both structural and non-structural are to be planned in order to find a climate resilient environment for food security and livelihood security.

8. RECOMMENDATIONS AND LIMITATIONS

The study has been carried out considering 13% increase of precipitation for the whole GBM basin area, according to the prediction of 4^{th} IPCC report. In reality it may vary for the whole GBM basin. In this study ice melt, bank erosion and river sedimentation were not considered. The study results are indicative which need more analysis for further improvement.

A further study can be done on the following issues:

- Similar study can be done for all districts instead of seven;
- Impact assessment of climate change on drought;
- Develop a flood level and risk map based on future projected climatic parameters for all districts;
- Floodplain zoning depending on various levels of vulnerability;
- Develop climate resilient cropping patterns suited to different regions of the country depends on monsoon flooding, drought and salinity;
- Assess the drainage capacity of all cities/towns to investigate structural and non-structural causes of water logging within the cities/towns and their immediate surroundings using hydro-dynamic models;
- Impact assessment of sea level rise on salinity intrusion in the coastal area of Bangladesh and eventually impact on agriculture, fisheries, ecology and livelihood of coastal community;
- Identification of erosion prone area due to sea level rise and climate change in the coastal area of Bangladesh and
- Assess potential threats to fish spawning and growth of fish in the coastal zone and brackish water due to salinity intrusion.

REFERENCES

1. 4th IPCC (2007), Regional Impacts of Climate change, Chapter 11.
2. 4th IPCC (2007), Technical Summary, "A Report of Working Group 1 of the Intergovernmental Panel on Climate Change".
3. Agrawala, S., Ota, T., Ahmed, A.U., Smith, J. and Aalst, M. van, (2003), Development and Climate Change in Bangladesh: Focus on Coastal Flooding and the Sundarbans. COM/ENV/EPOC/DCD/DAC (2003)3/Final, OECD, Paris.
4. Ali, A., 2001, "Vulnerability of Bangladesh Coastal Region to Climate Change with Adaption options", Paper presented at Survas/LOICZ Joint Conference on Coastal Impacts of Climate Change. (http://www.survas.mdx.ac.uk).
5. Alam, M. and A. Samad. 1996. Subsidence of the Ganges – Brahmaputra delta and impact of possible sea level rise on the coastal area of Bangladesh. *Dhaka University Journal of Science*.
6. Al-Farouq and Huq (1996), "Adaptation to climate change in the coastal resources sector of Bangladesh: Some issue and problems".
7. Bangladesh Country Report (1994), Climate Change in Asia.
8. BUP/CEARS/CRU, 1994. Bangladesh: Greenhouse Effect and Climate Change.Briefing Documents, No.1-7, *Bangladesh Unnayan Parishad*, Dhaka.
9. Climate Change Cell/DOE/CDMP, 2006. Workshop on climate change impact modelling, Report and presentations.
10. Hoque, M, 1982. Tectonic Setup of Bangladesh and its Relation to Hydrocarbon Accumulation. *Centre for Policy Research, DU.*
11. Hoque, M, and M. Alam, 1997. Subsidence in the lower Deltaic areas of Bangladesh. *Marine Geodesy.*
12. Islam, M. Rafiqul, (2004), Where Land Meets the Sea: A Profile of the Coastal Zone of Bangladesh.
13. IUCN Bangladesh, 2003. Impact of Climate Change and Variability on Sedimentation in Coastal Zone and Coastal Zone Management. *IUCN Bangladesh Country Office, Dhaka*.
14. IWM (2003), VOL: VII, Validation Report 2001-2002, Updating and Validation of General Model and Six Regional Models, Bangladesh Water Development Board.
15. IWM (2004), Technical feasibility study with hydraulic modelling for Meghna-Tentulia river bank protection project.
16. IWM (2005), Impact assessment of climate changes on the coastal zone of Bangladesh.
17. IWM & CEGIS (2007), Investigating the Impact of Relative Sea-Level Rise on Coastal Communities and their Livelihoods in Bangladesh.

18. J.T. Houghton, Y. Ding, D.J Griggs, M. Nogeur, P.J. van der Linden and D. Xiaosu (Eds) (2001), 3rd IPCC – Inter Governmental Panel on Climate Change – The Scientific Basis, Cambridge University Press, pp944.

19. Khan, A.A. and M.A.Hoque, 2002. Quaternary Paleo-geography and geohazard scenario of the Bengal delta of Bangladesh. *Bangladesh Geographical Society Conference Paper.*

20. MES II, (June 2001), Hydro-Morphological Dynamics of the Meghna Estuary. Submitted to Ministry of Water Resources, Bangladesh Water Development Board, by DHV Consultants and associates.

21. Morgan, J.P. and W.G. McIntire, 1959. Quaternary Geology of the Bengal Basin, *Geological Society of America.*

22. NWMP (2000); Volume 4, Annex C: Land and Water Resources.

23. OECD, 2003, "Development and climate change in Bangladesh: Focus on coastal flooding and the Sundarbans".

24. PDO-ICZMP: Living in the Coast People and Liveihoods.

25. R. Ramachandran (2001), Impact of climate change in Asia, Volume 18 – Issue 07, Mar. 31-Apr.13, 2001, Indian National Magazine.

26. Ronald J. Cox and Peter R. Horton (1999), "Implications of climate change on coastal management", COPEDEC V.

27. SMRC, (2000), The Vulnerability Assessment of the SAARC Coastal Region due to Sea Level Rise: Bangladesh Case. SMRC-NO.3, SMRC Publication.

28. SMRC, (2003), Proceeding of SAARC Seminar on Climate Variability in the South Asian Region and its Impacts 10-12 December 2002, SMRC.

29. SWMC (2000), Second Coastal Embankment Rehabilitation Project.

30. Umitsu, M, 1993. Late Quaternary Sedimentary Environments and Landforms in Ganges Delta. *Sedimentary Geology*.

31. World Bank, (2000), Bangladesh: Climate Change & Sustainable Development, South Asia Rural Development Team, World Bank Office, Dhaka, Report No. 21104 BD.

Appendix-A

Impact on land type for every upazila of seven districts in tabular form

Table A.1: Impact on land type in each upazila under Gaibandha District

Upazilas	Area (km^2)		Land Type (km^2)				
			F0	F1	F2	F3	F4
Fulchhari	306.53	2005	0.09	9.90	12.51	0.54	0.00
		2040	0.90	11.79	35.64	4.23	0.00
		% increase	significant	19.09	184.89	683.33	
Gaibandha Sadar	320.25	2005	19.62	92.52	77.13	6.84	0.00
		2040	19.62	88.47	87.57	17.28	0.00
		% increase	0.00	-4.38	13.54	152.63	
Gobindaganj	481.66	2005	13.59	75.51	111.69	30.96	0.00
		2040	7.83	51.57	119.70	61.65	0.09
		% increase	-42.38	-31.70	7.17	99.13	
Palashbari	190.67	2005	12.24	57.33	67.32	23.31	0.36
		2040	7.83	37.62	75.42	52.29	0.81
		% increase	-36.03	-34.38	12.03	124.32	125.00
Sadullapur	227.97	2005	5.22	56.43	111.51	26.10	0.00
		2040	4.95	44.19	103.86	55.89	0.00
		% increase	-5.17	-21.69	-6.86	114.14	
Sughatta	225.67	2005	2.61	46.62	57.33	11.43	0.00
		2040	1.44	24.93	78.21	23.04	0.00
		% increase	-44.83	-46.53	36.42	101.57	
Sundarganj	426.52	2005	21.06	76.50	42.30	4.86	0.00
		2040	30.87	74.70	70.47	10.35	0.00
		% increase	46.58	-2.35	66.60	112.96	

Table A.2: Impact on land type in each upazila under Sirajganj District

Upazilas	Area (km^2)		Land Type (km^2)				
			F0	F1	F2	F3	F4
Belkuchi	164.31	2005	9.54	53.19	33.12	4.77	0.00
		2040	5.31	35.01	61.74	15.75	0.00
		% increase	-44.34	-34.18	86.41	230.19	
Chauhali	243.67	2005	1.26	15.03	26.91	16.11	1.17
		2040	0.90	10.44	32.31	16.20	1.44
		% increase	-28.57	-30.54	20.07	0.56	23.08
Kamarkhanda	91.61	2005	9.81	63.72	50.31	8.10	0.00
		2040	4.14	40.86	73.44	21.69	0.00
		% increase	-57.80	-35.88	45.97	167.78	
Kazipur	368.63	2005	9.81	63.72	50.31	8.10	0.00
		2040	4.14	40.86	73.44	21.69	0.00
		% increase	-57.80	-35.88	45.97	167.78	
Raiganj	267.83	2005	5.85	57.69	96.39	32.76	0.36
		2040	4.14	37.53	120.96	72.63	0.90
		% increase	-29.23	-34.95	25.49	121.70	150.00
Shahjadpur	324.47	2005	2.52	25.47	96.30	97.65	7.56
		2040	0.45	7.29	63.63	144.36	16.38
		% increase	-82.14	-71.38	-33.93	47.83	116.67
Sirajganj Sadar	325.77	2005	10.26	48.51	83.43	41.40	0.00
		2040	4.77	36.81	83.84	68.85	0.18
		% increase	-53.51	-24.12	0.49	66.30	
Tarash	297.2	2005	10.62	42.48	73.35	87.12	1.98
		2040	10.35	36.27	78.84	130.86	6.75
		% increase	-2.54	-14.62	7.48	50.21	240.91
Ullahpara	414.43	2005	5.49	66.24	194.94	128.97	1.17
		2040	0.90	15.75	132.84	248.40	9.72
		% increase	-83.61	-76.22	-31.86	92.60	significant

Table A.3: Impact on land type in each upazila under Pabna District

Upazilas	Area (km^2)		Land Type (km^2)				
			F0	F1	F2	F3	F4
Atgharia	186.15	2005	9.18	25.29	23.40	23.67	8.64
		2040	17.37	48.06	37.71	30.15	13.68
		% increase	89.22	90.04	61.15	27.38	58.33
Bera	248.6	2005	0.00	10.44	77.94	49.23	8.91
		2040	0.00	0.00	39.33	80.55	26.64
		% increase		-100.00	-49.54	63.62	198.99
Bhangura	120.2	2005	1.89	11.43	31.50	60.12	5.67
		2040	0.18	4.14	23.04	65.61	18.45
		% increase	-90.48	-63.78	-26.86	9.13	225.40
Chatmohar	314.32	2005	11.70	43.20	83.70	91.53	10.71
		2040	7.56	38.88	83.97	127.98	26.01
		% increase	-35.38	-10.00	0.32	39.82	142.86
Faridpur	145.47	2005	0.45	9.63	35.37	75.69	15.03
		2040	0.18	1.17	23.22	77.76	34.20
		% increase	-60.00	-87.85	-34.35	2.73	127.54
Ishwardi	256.9	2005	0.09	12.60	6.75	0.09	0.00
		2040	12.87	25.65	4.41	0.09	0.00
		% increase		103.57	-34.67	0.00	
Santhia	331.56	2005	13.41	55.44	109.08	117.09	12.51
		2040	3.87	26.19	89.37	162.27	42.48
		% increase	-71.14	-52.76	-18.07	38.59	239.57
Sujanagar	334.4	2005	2.43	13.05	80.46	118.89	63.54
		2040	0.00	0.63	33.30	129.51	115.92
		% increase	-100.00	-95.17	-58.61	8.93	82.44
Pabna Sadar	443.9	2005	22.41	38.88	38.88	17.37	1.17
		2040	13.32	54.18	76.59	48.06	4.14
		% increase	-40.56	39.35	96.99	176.68	253.85

Table A.4: Impact on land type in each upazila under Faridpur District

Upazilas	Area (km^2)		Land Type (km^2)				
			F0	F1	F2	F3	F4
Faridpur Sadrar	396	2005	2.70	15.57	6.66	6.30	1.89
		2040	3.33	16.38	12.96	7.47	2.79
		% increase	23.33	5.20	94.59	18.57	47.62
Boalmari	272.34	2005	0.72	3.96	3.06	0.00	0.00
		2040	2.52	3.69	3.87	0.00	0.00
		% increase	250.00	-6.82	26.47		
Alfadanga	136	2005	4.14	10.26	8.55	0.18	0.00
		2040	11.52	18.00	19.80	2.16	0.00
		% increase	178.26	75.44	131.58	significant	
Madhukhali	230.2	2005	0.18	0.81	0.99	0.00	0.00
		2040	0.54	0.90	0.99	0.09	0.00
		% increase	200.00	11.11	0.00		
Bhanga	216.34	2005	1.80	18.27	76.86	77.49	8.46
		2040	3.42	27.27	71.73	80.64	6.84
		% increase	90.00	49.26	-6.67	4.07	-19.15
Nagarkanda	379.02	2005	6.03	38.07	86.76	35.82	0.00
		2040	4.41	34.74	84.96	50.13	0.09
		% increase	-26.87	-8.75	-2.07	39.95	
Char Bhadrasan	183	2005	10.53	21.15	13.95	0.54	0.00
		2040	6.39	34.74	21.15	3.42	0.00
		% increase	-39.32	64.26	51.61	significant	
Sadarpur	290.21	2005	5.94	48.51	92.97	66.24	0.00
		2040	1.53	27.99	93.33	96.75	0.63
		% increase	-74.24	-42.30	0.39	46.06	

Table A.5: Impact on land type in each upazila under Sunamganj District

Upazilas	Area (km^2)		Land Type (km^2)				
			F0	F1	F2	F3	F4
Bishwamvarpur	194.25	2005	2.52	8.91	17.28	53.55	12.96
		2040	3.42	9.54	15.93	52.56	18.18
		% increase	35.71	7.07	-7.81	-1.85	40.28
Chhatak	434.76	2005	25.20	85.05	99.18	27.72	0.00
		2040	19.35	82.26	115.83	44.64	0.36
		% increase	-23.21	-3.28	16.79	61.04	
Derai	420.93	2005	4.68	25.65	81.54	202.14	30.33
		2040	2.88	18.00	63.54	215.37	50.83
		% increase	-38.46	-29.82	-22.08	6.54	67.59
Dharmapasha	496.03	2005	1.26	8.46	53.91	236.70	139.86
		2040	2.25	7.65	42.48	231.21	160.65
		% increase	78.57	-9.57	-21.20	-2.32	14.86
Dowarabazar	281.4	2005	11.07	52.56	67.50	34.65	0.99
		2040	7.92	52.11	75.42	50.40	2.07
		% increase	-28.46	-0.86	11.73	45.45	109.09
Jagannathpur	368.27	2005	13.05	74.61	114.30	92.25	10.08
		2040	11.97	63.81	123.75	104.85	14.40
		% increase	-8.28	-14.48	8.27	13.66	42.86
Jamalganj	338.74	2005	0.90	4.95	18.90	117.72	132.03
		2040	0.81	3.69	15.21	102.24	153.45
		% increase	-10.00	-25.45	-19.52	-13.15	16.22
Tahirpur	313.7	2005	2.34	12.87	19.89	76.41	122.13
		2040	3.06	11.16	20.07	72.27	130.05
		% increase	30.77	-13.29	0.90	-5.42	6.48
Sullah	260.74	2005	0.45	4.14	48.69	170.28	15.66
		2040	0.00	1.71	25.83	178.20	33.57
		% increase	-100.00	-58.70	-46.95	4.65	114.37
Sunamganj Sadar	560.76	2005	20.70	94.23	178.29	166.68	8.91
		2040	13.50	74.61	174.24	216.72	12.15
		% increase	-34.78	-20.82	-2.27	30.02	36.36

Table A.6: Impact on land type in each upazila under Satkhira District

Upazilas	Area (km^2)		Land Type (km^2)				
			F0	F1	F2	F3	F4
Satkhira Sadar	400.82	2005	6.75	43.74	61.56	147.78	0.00
		2040	4.86	26.82	71.10	161.55	0.00
		% increase	-28.00	-38.68	15.50	9.32	
Assasuni	402.36	2005	0.00	0.09	1.98	91.26	0.00
		2040	0.00	0.00	1.35	91.44	0.45
		% increase		-100.00	-31.82	0.20	
Debhata	176.33	2005	0.90	5.67	41.31	100.80	0.00
		2040	0.36	5.04	25.11	118.17	0.00
		% increase	-60.00	-11.11	-39.22	17.23	
Kalaroa	232.64	2005	5.67	17.19	21.96	4.50	0.00
		2040	12.51	26.55	25.56	5.94	0.00
		% increase	120.63	54.45	16.39	32.00	
Kaliganj	333.79	2005	0.09	7.20	33.84	232.47	0.00
		2040	0.00	4.05	29.16	240.39	0.00
		% increase	-100.00	-43.75	-13.83	3.41	
Shyamnagar	1968.24	2005	0.00	0.09	169.11	1139.31	0.09
		2040	0.00	0.00	1.71	1306.53	0.36
		% increase		-100.00	-98.99	14.68	300.00
Tala		2005	22.50	47.52	62.55	128.25	0.00
		2040	9.99	66.24	62.01	139.95	0.00
		% increase	-55.60	39.39	-0.86	9.12	

Table A.7: Impact on land type in each upazila under Barisal District

Upazilas	Area (km^2)		Land Type (km^2)				
			F0	F1	F2	F3	F4
Agailjhara	161.82	2005	8.10	79.29	68.49	1.35	0.00
		2040	1.17	32.22	115.20	12.24	0.00
		% increase	-85.56	-59.36	68.20	significant	
Babuganj	164.88	2005	20.70	65.07	8.91	0.00	0.00
		2040	22.77	76.05	19.98	0.00	0.00
		% increase	10.00	16.87	124.24		
Bakerganj	417.21	2005	8.37	266.85	80.82	0.63	0.00
		2040	1.08	123.12	230.49	3.15	0.00
		% increase	-87.10	-53.86	185.19	significant	
Banaripara	134.32	2005	0.00	16.56	109.08	0.54	0.00
		2040	0.00	3.87	119.25	3.06	0.00
		% increase		-76.63	9.32	significant	
Gournadi	144.14	2005	21.51	56.25	12.96	0.00	0.00
		2040	14.13	60.48	41.04	0.54	0.00
		% increase	-34.31	7.52	216.67		
Hizla	515.36	2005	2.52	43.56	76.23	62.46	0.00
		2040	0.18	19.44	92.34	72.90	0.00
		% increase	-92.86	-55.37	21.13	16.71	
Barisal Sadar	307.59	2005	30.33	171.45	40.95	3.24	0.00
		2040	9.81	161.82	76.14	6.21	0.00
		% increase	-67.66	-5.62	85.93	91.67	
Mehendiganj	435.79	2005	2.61	125.46	148.05	6.66	0.00
		2040	0.99	70.29	199.71	12.42	0.00
		% increase	-62.07	-43.97	34.89	86.49	
Muladi	261.02	2005	13.59	68.49	75.69	1.71	0.00
		2040	9.27	53.19	110.43	4.86	0.00
		% increase	-31.79	-22.34	45.90	184.21	
Wazipur	248.35	2005	9.90	82.35	128.25	1.53	0.00
		2040	6.84	58.32	157.23	10.80	0.00
		% increase	-30.91	-29.18	22.60	significant	

Appendix-B

Impact on land type for every upazila of seven districts in map

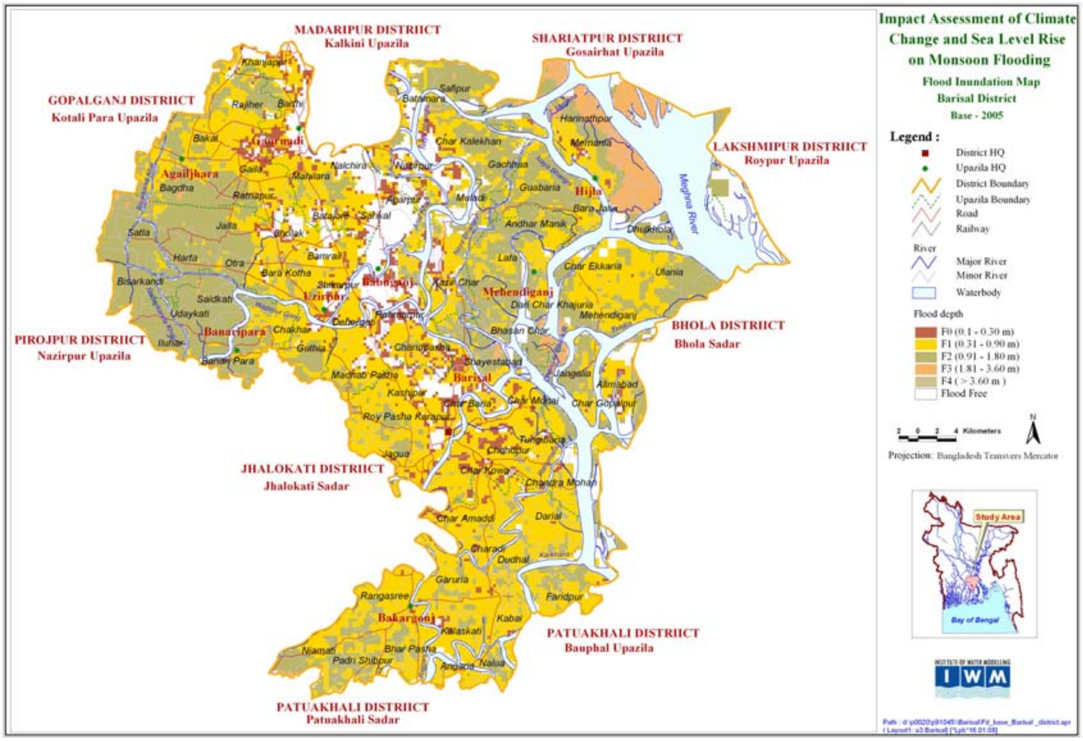

Figure B1: Inundated Area Base Condition, Barisal District (Average Flood, Year 2005)

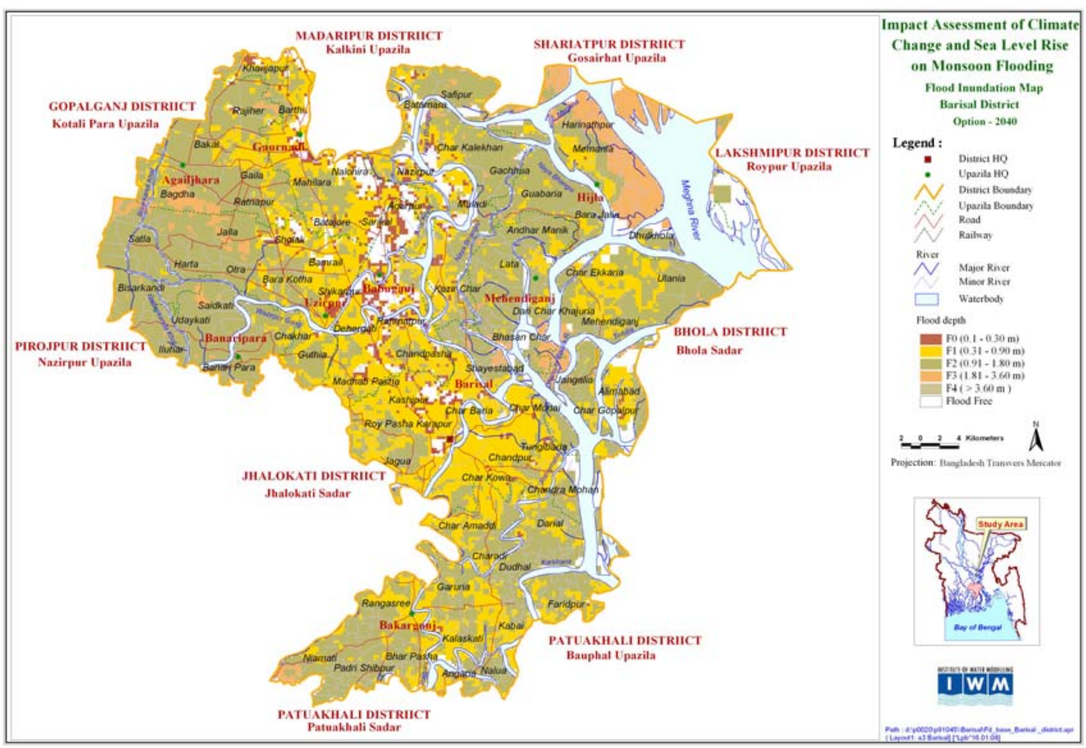

Figure B2: Impact on Inundated Area due to Climate Change, Barisal District (2040)

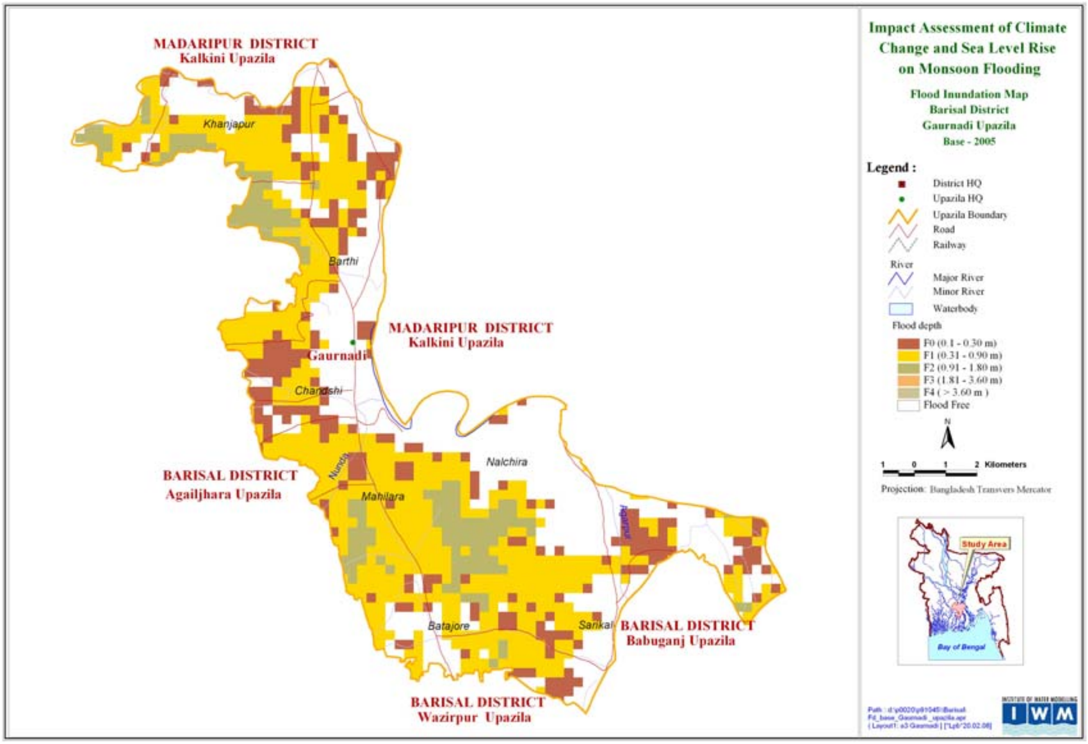

Figure B3: Inundated Area Base Condition, Gaurnadi Upazila in Barisal (Average Flood, Year 2005)

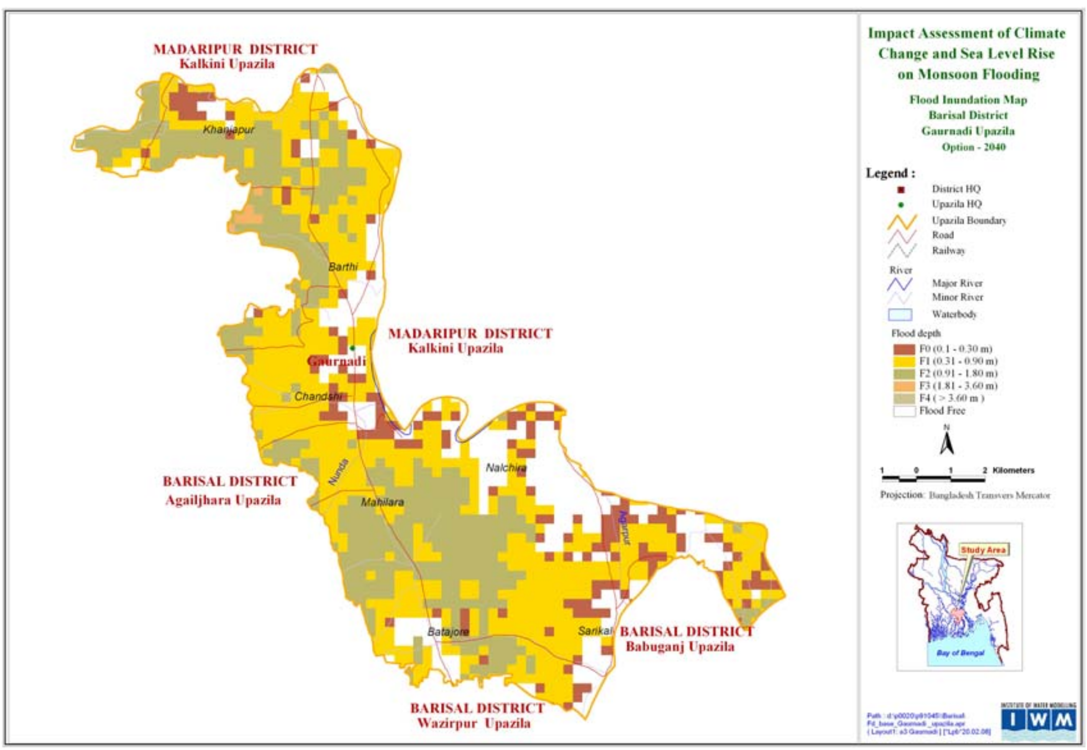

Figure B4: Impact on Inundated Area due to Climate Change Condition, Gaurnadi, Barisal (2040)

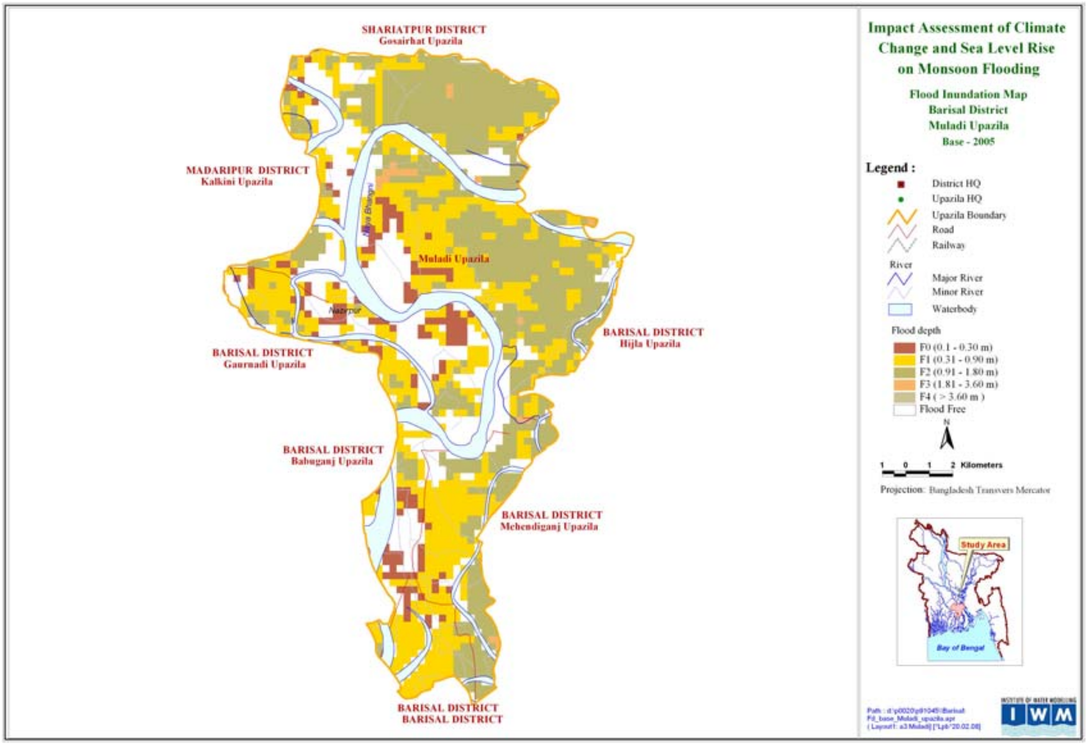

Figure B5: Inundated Area Base Condition, Muladi Upazila in Barisal (Average Flood, Year 2005)

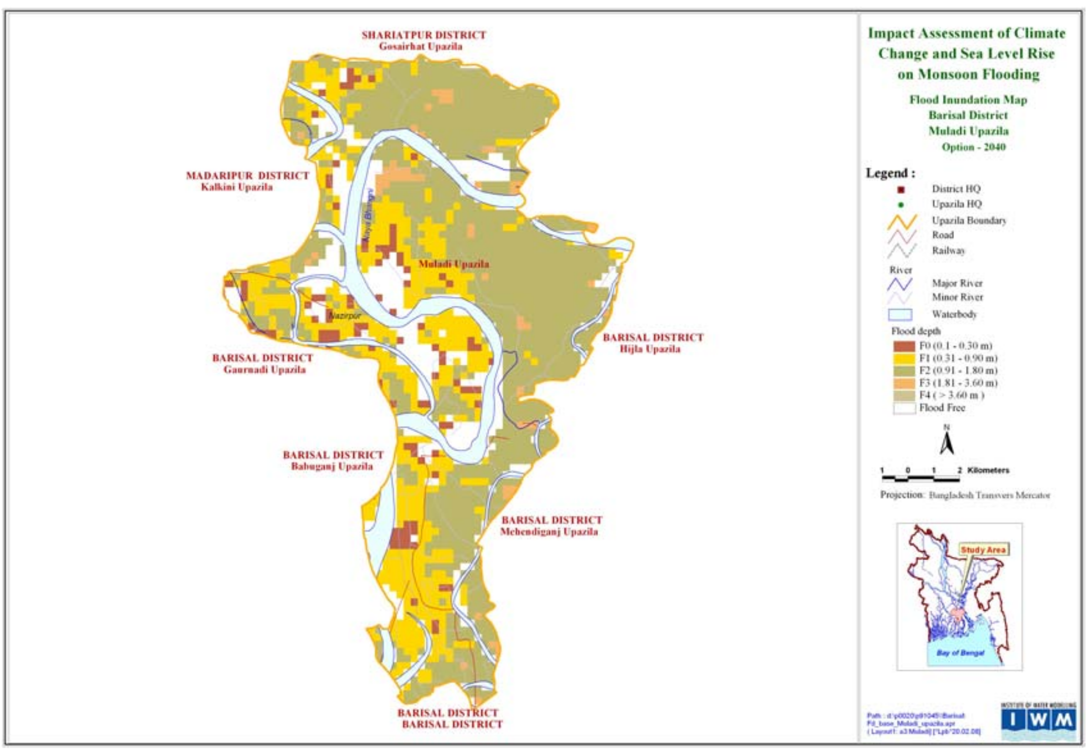

Figure B6: Impact on Inundated Area due to Climate Change, Muladi Upazila in Barisal (2040)

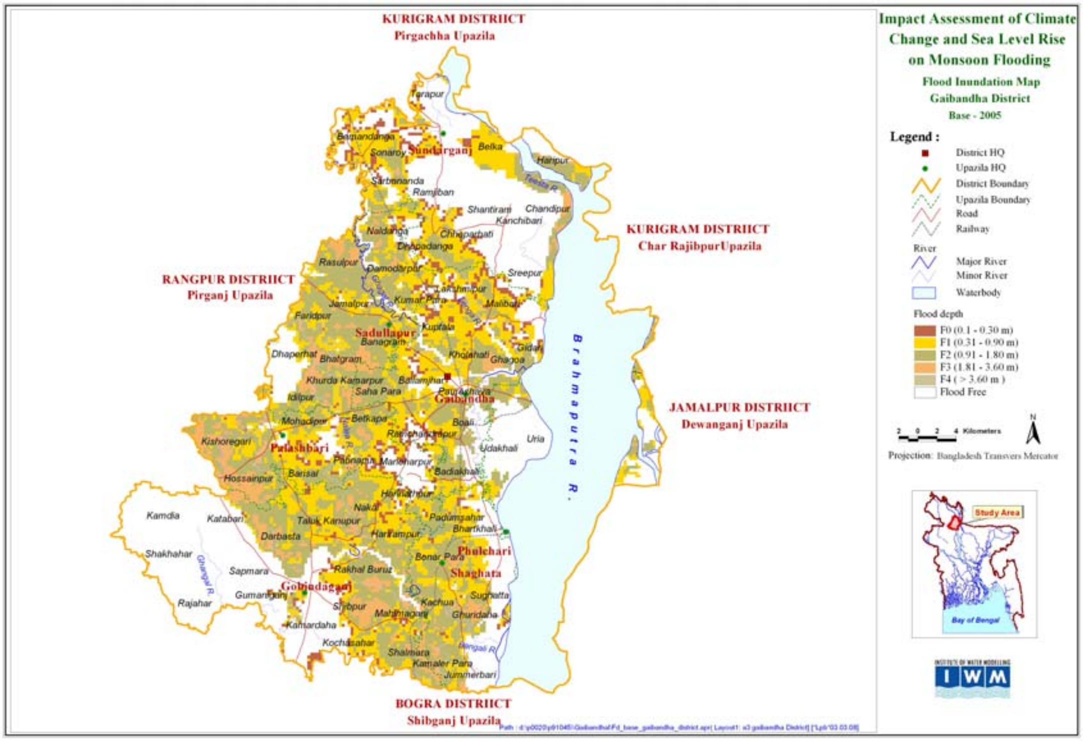

Figure B7: Inundated Area Base Condition, Gaibandha (Average Flood, Year 2005)

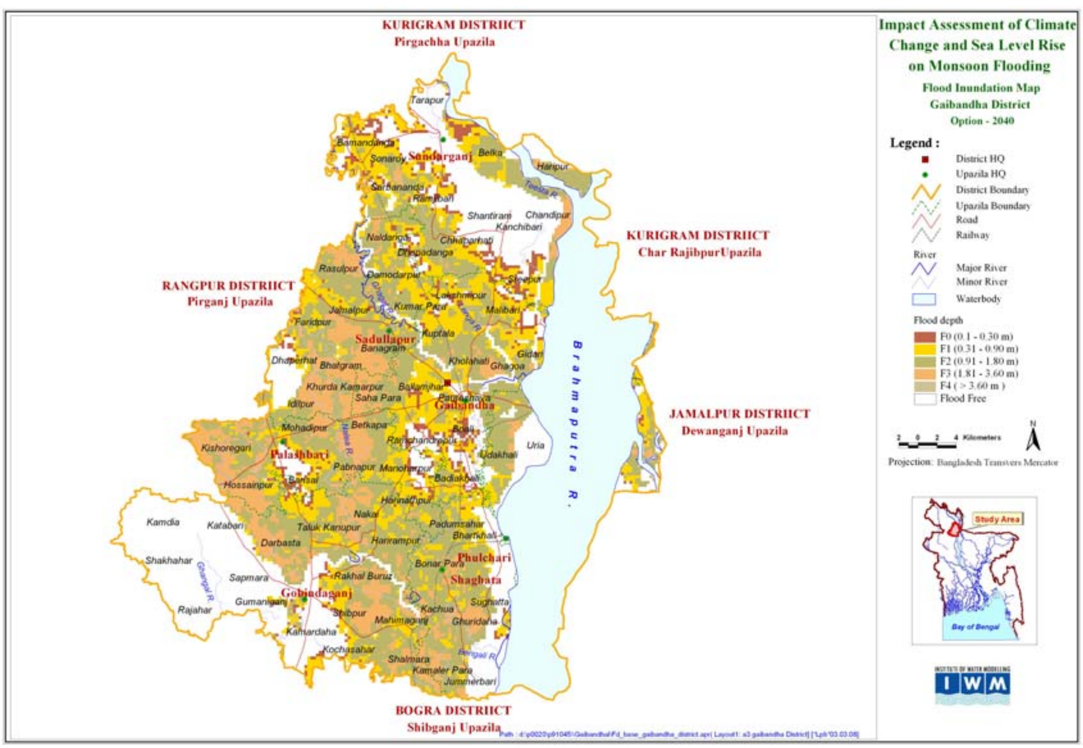

Figure B8: Impact on Inundated Area due to Climate Change, Gaibandha (2040)

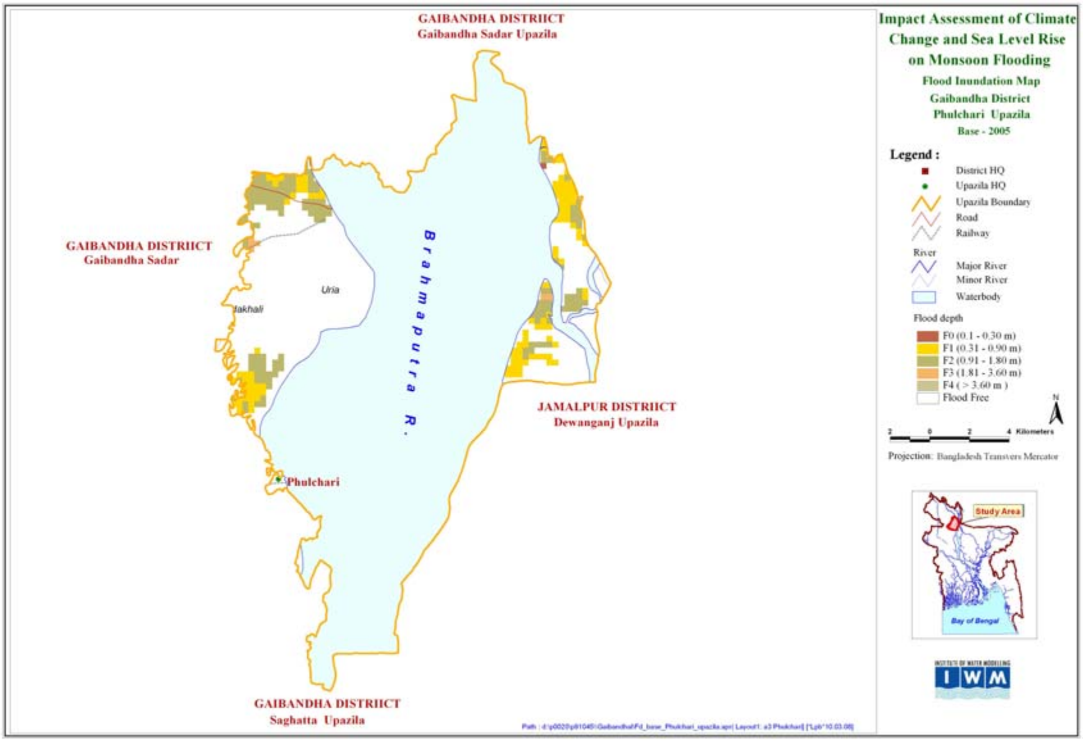

Figure B9: Inundated Area Base Condition, Fulchari Upazila in Gaibandha (Average Flood, Year 2005)

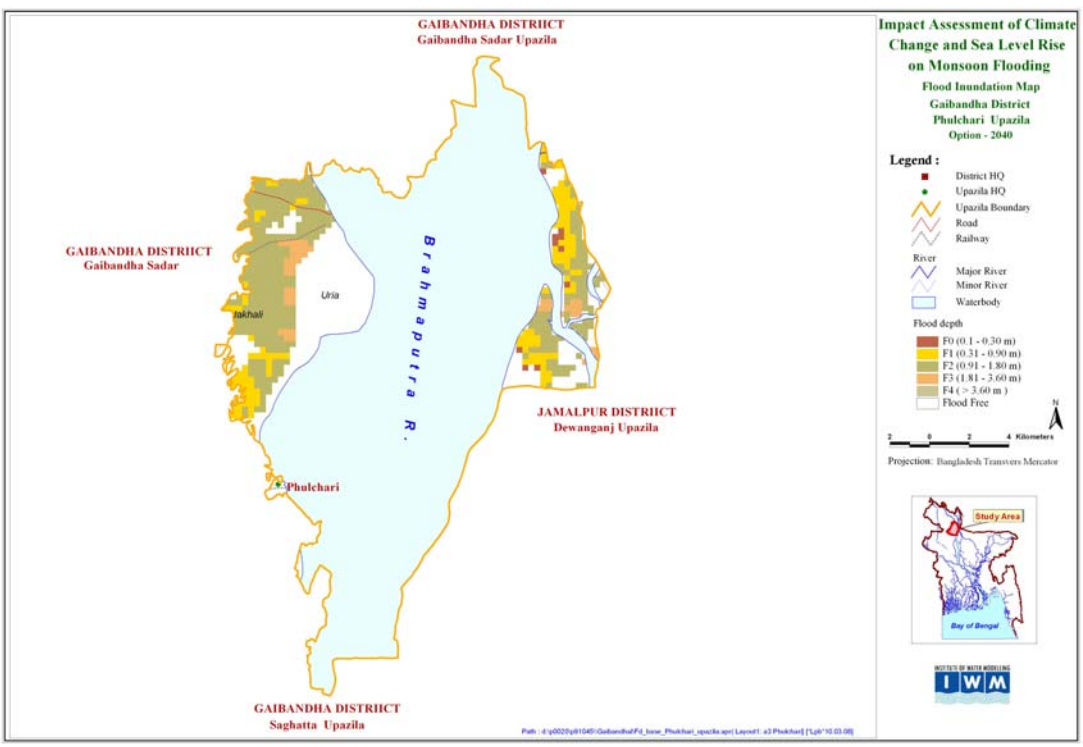

Figure B10: Impact on Inundated Area due to Climate Change, Fulchari Upazila in Gaibandha (2040)

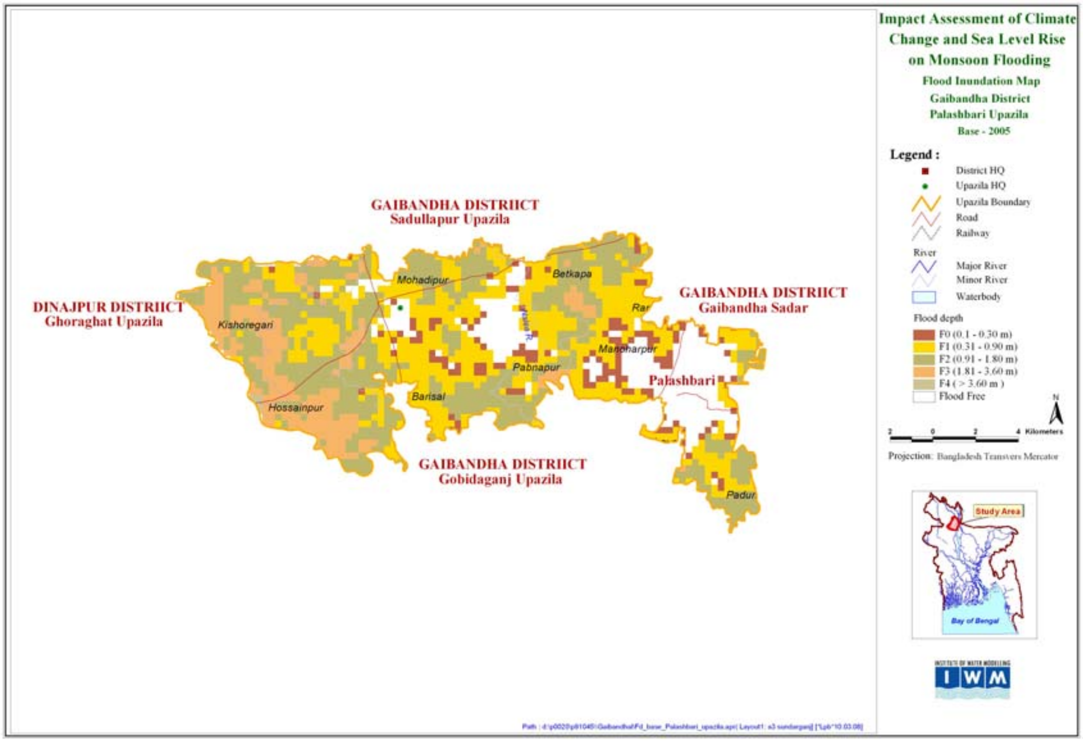

Figure B11: Inundated Area Base Condition, Palasbari Upazila in Gaibandha (Average Flood, Year 2005)

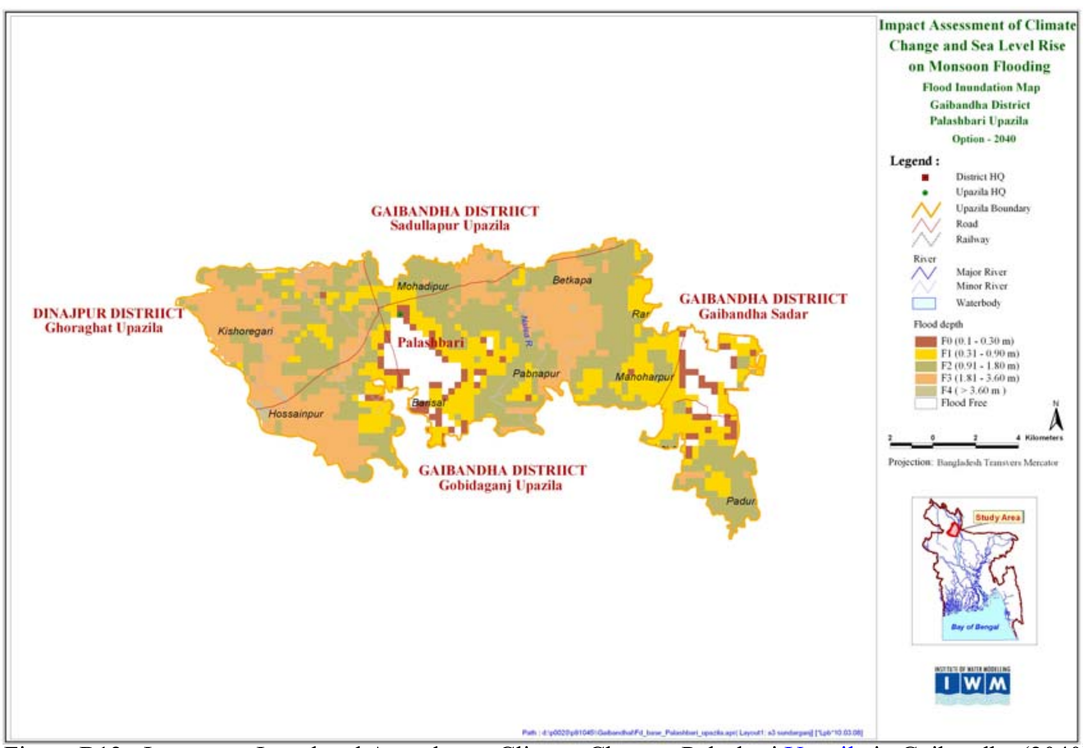

Figure B12: Impact on Inundated Area due to Climate Change, Palasbari Upazila in Gaibandha (2040)

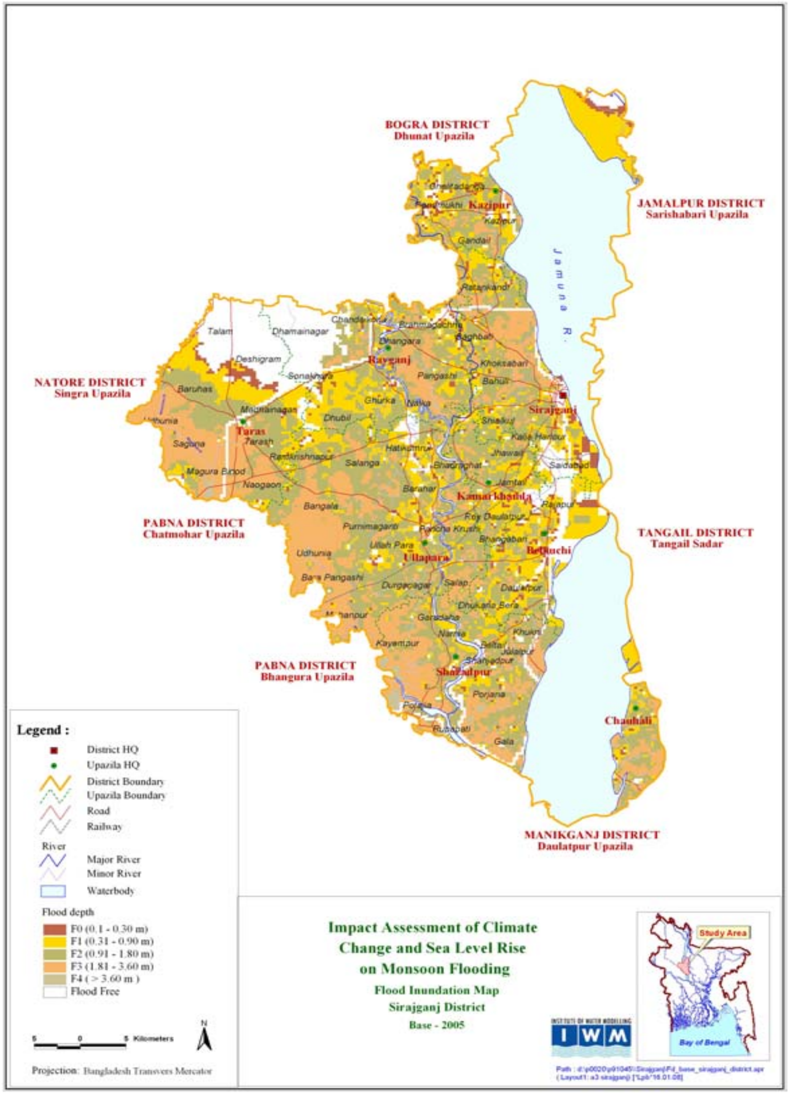

Figure B13: Inundated Area Base Condition, Sirajgang District (Average Flood Year, 2005)

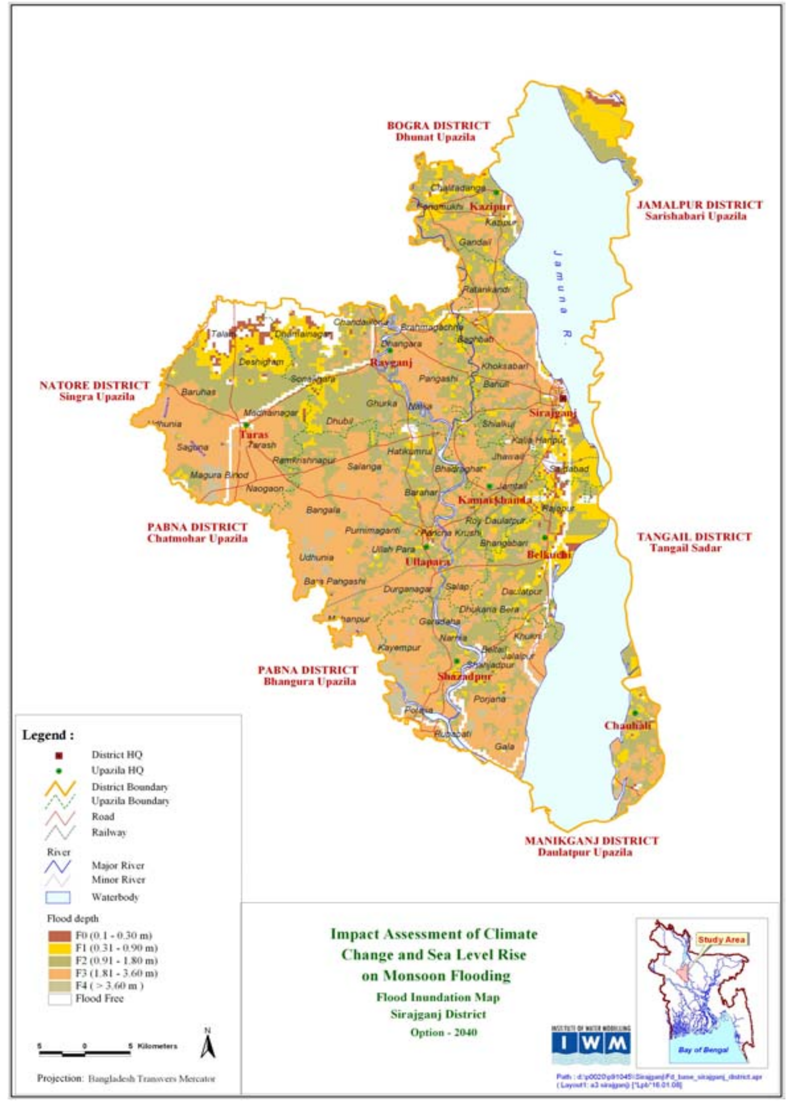

Figure B14: Impact on Inundated Area due Climate Change Condition, Sirajgang District (2040)

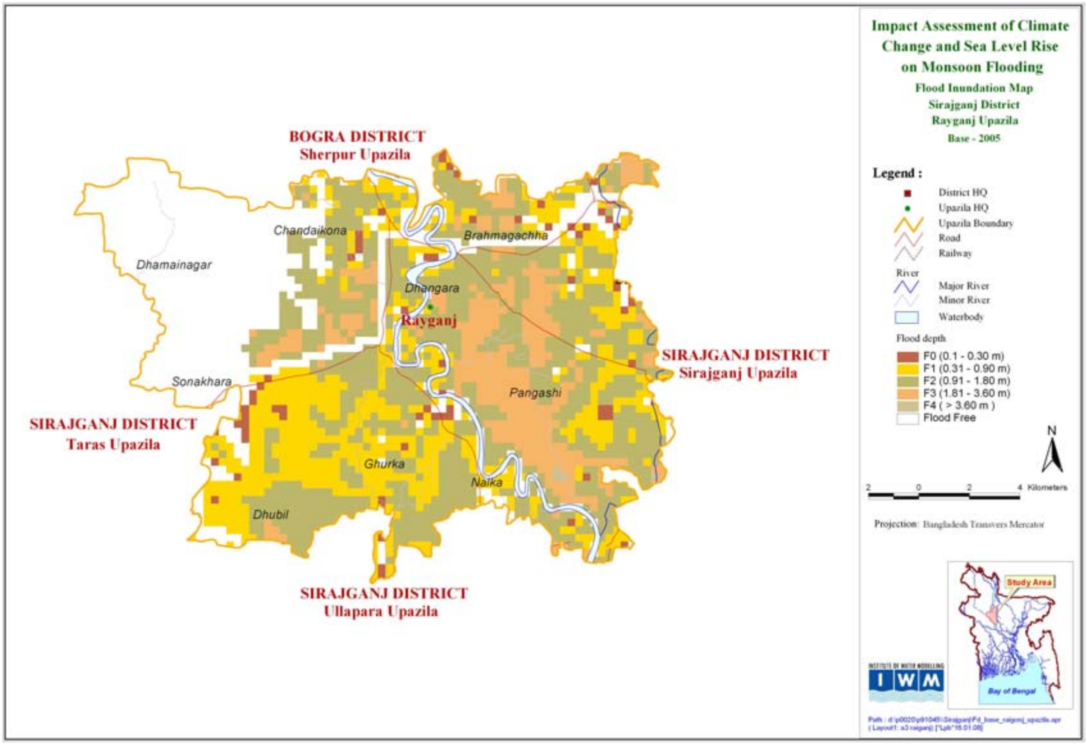

Figure B15: Inundated Area Base Condition, Raygang Upazila in Sirajgang (Average Flood Year, 2005)

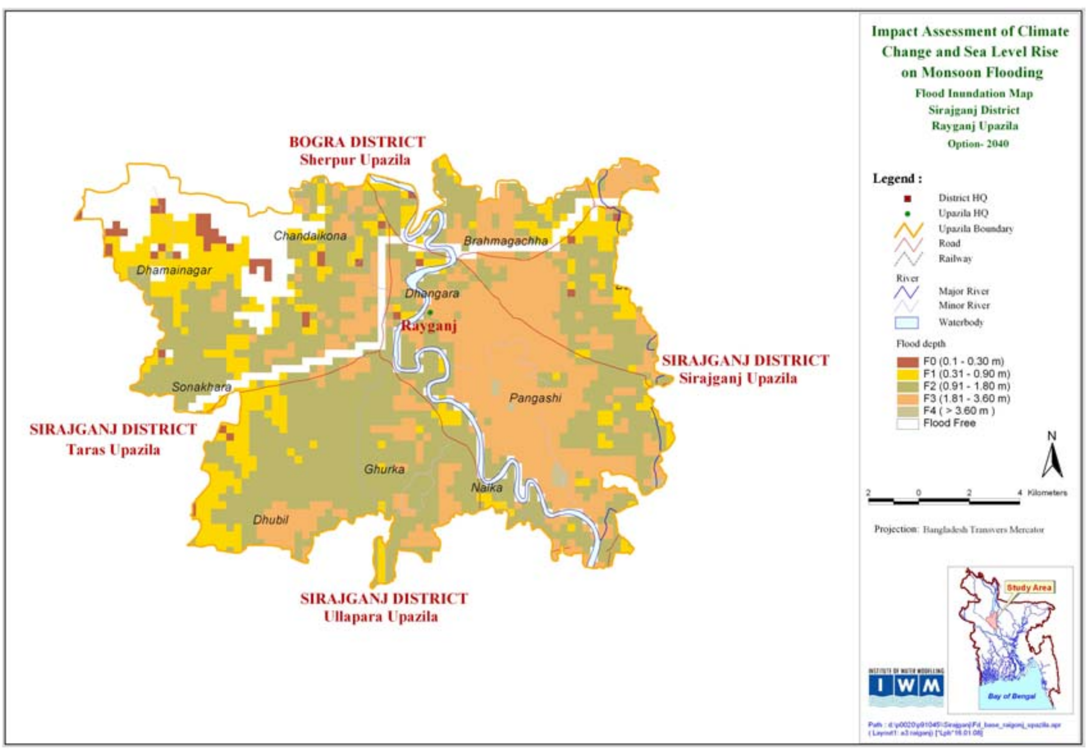

Figure B16: Impact on Inundated Area due Climate Change Condition, Raygang Upazila in Sirajgang (2040)

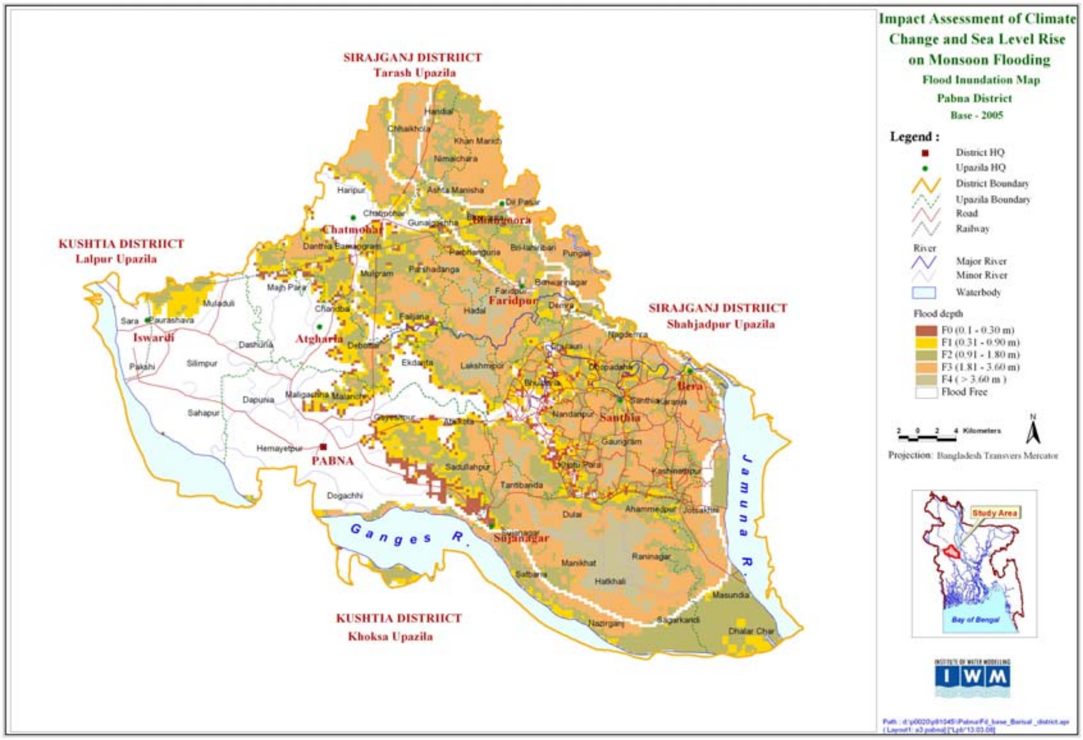

Figure B17: Inundated Area Base Condition, Pabna District (Average Flood, Year 2005)

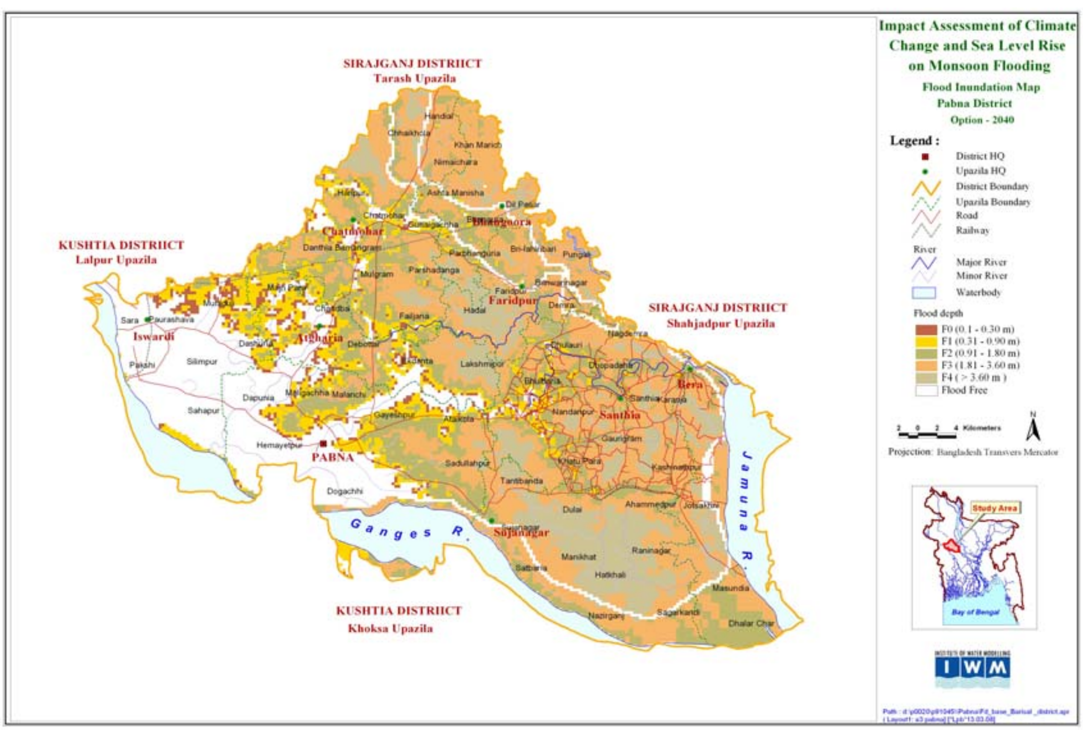

Figure B18: Impact on Inundated Area due to Climate Change Condition, Pabna District (2040)

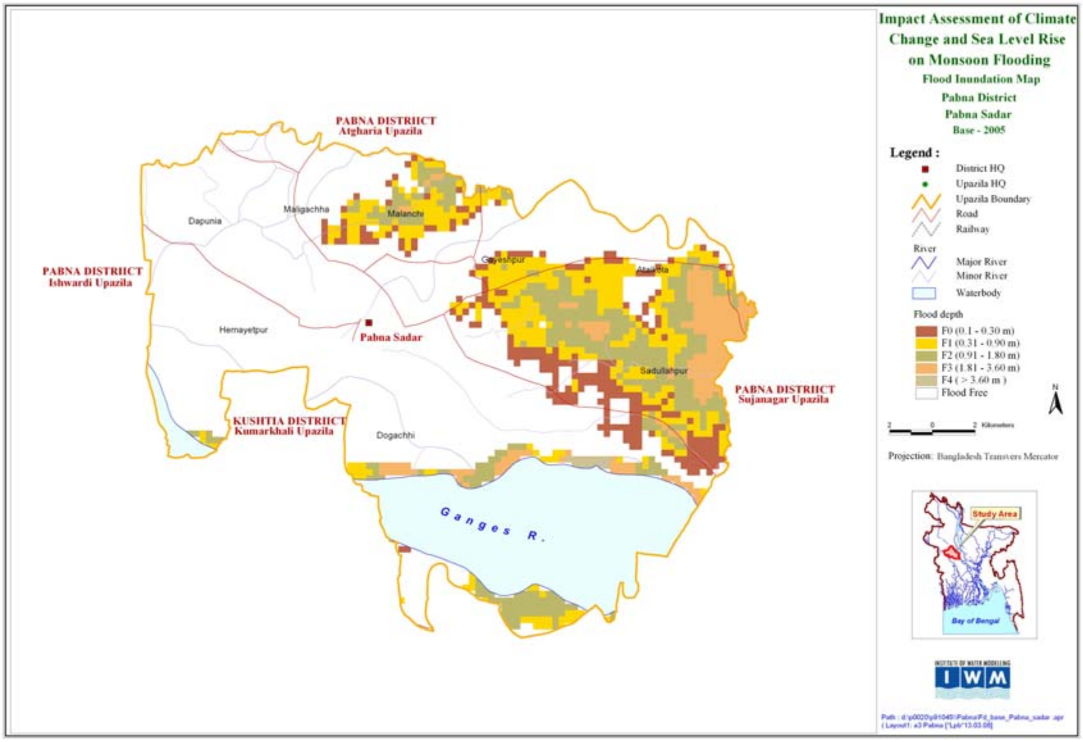

Figure B19: Inundated Area Base Condition, Pabna Sadar in Pabna (Average Flood, Year 2005)

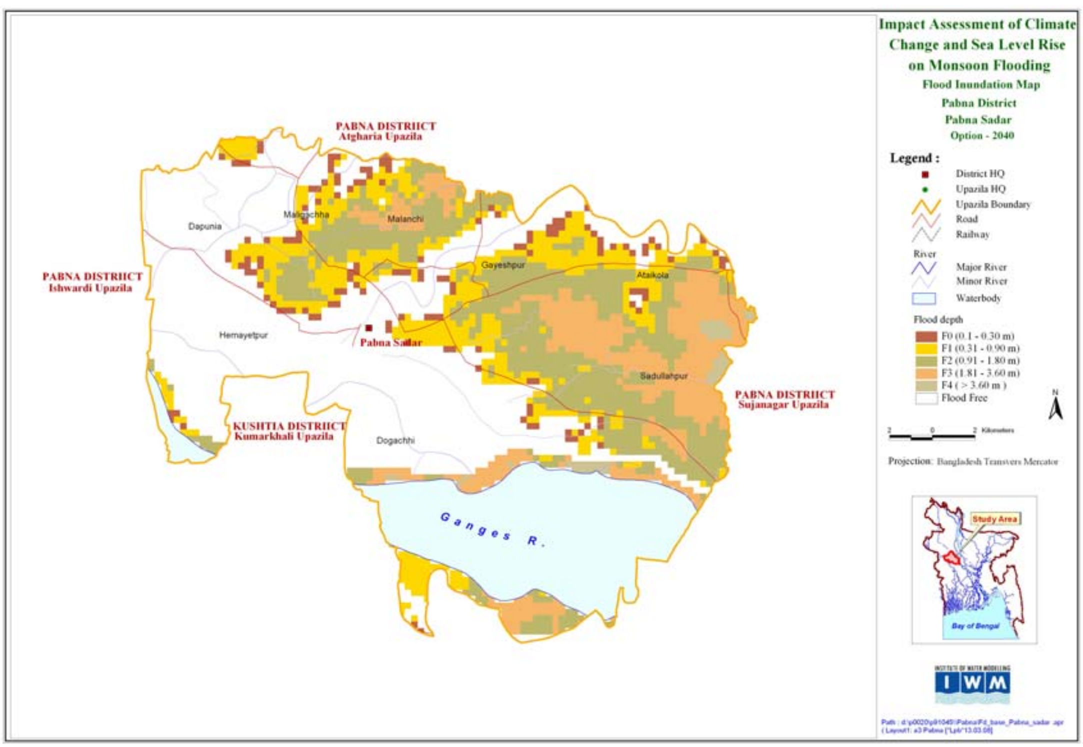

Figure B20: Impact on Inundated Area due to Climate Change Condition, Pabna Sadar in Pabna (2040)

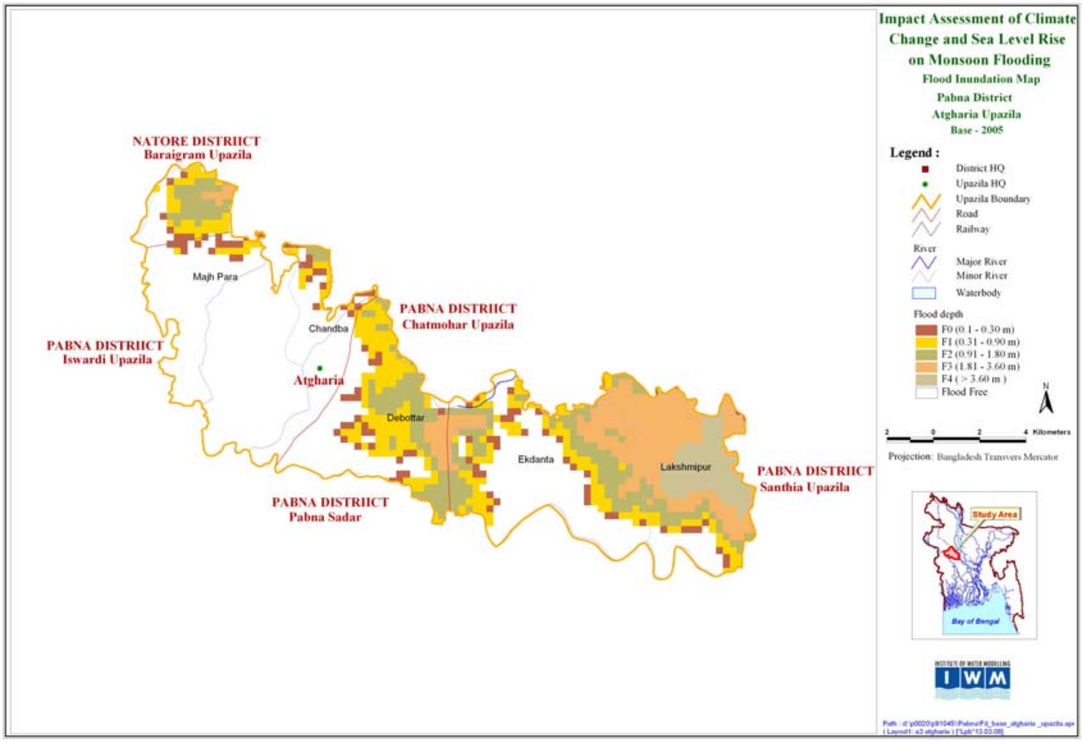

Figure B21: Inundated Area Base Condition, Atghari Upazila in Pabna (Average Flood, Year 2005)

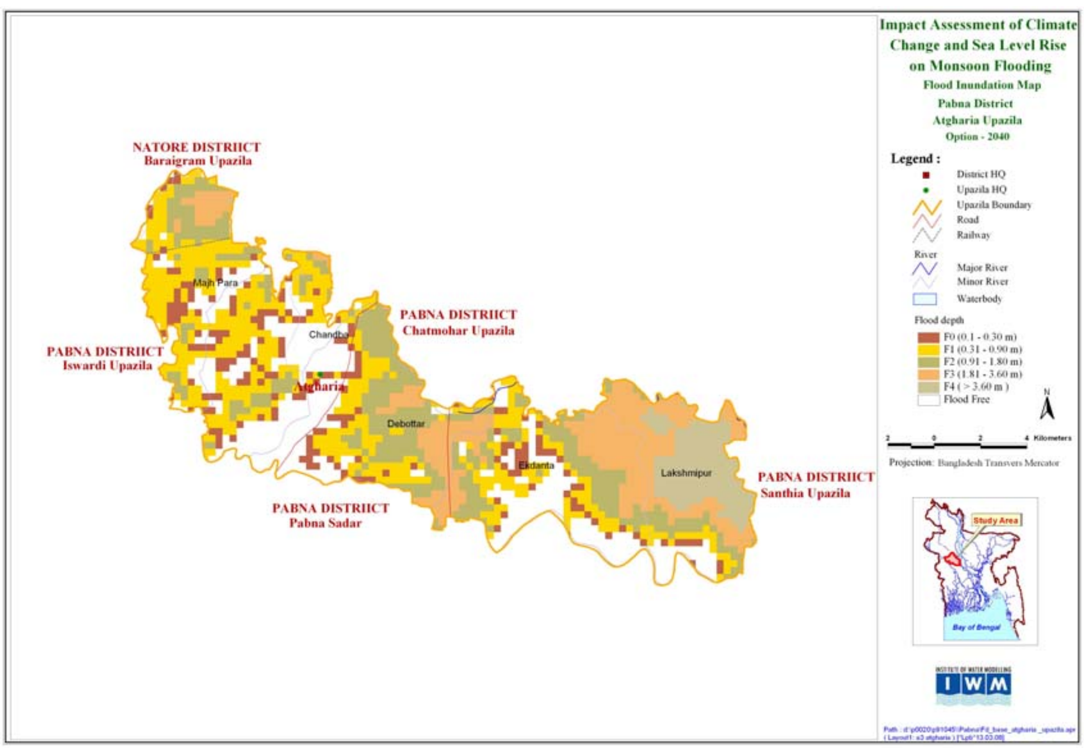

Figure B22: Impact on Inundated Area due to Climate Change Condition, Atghari, Pabna (2040)

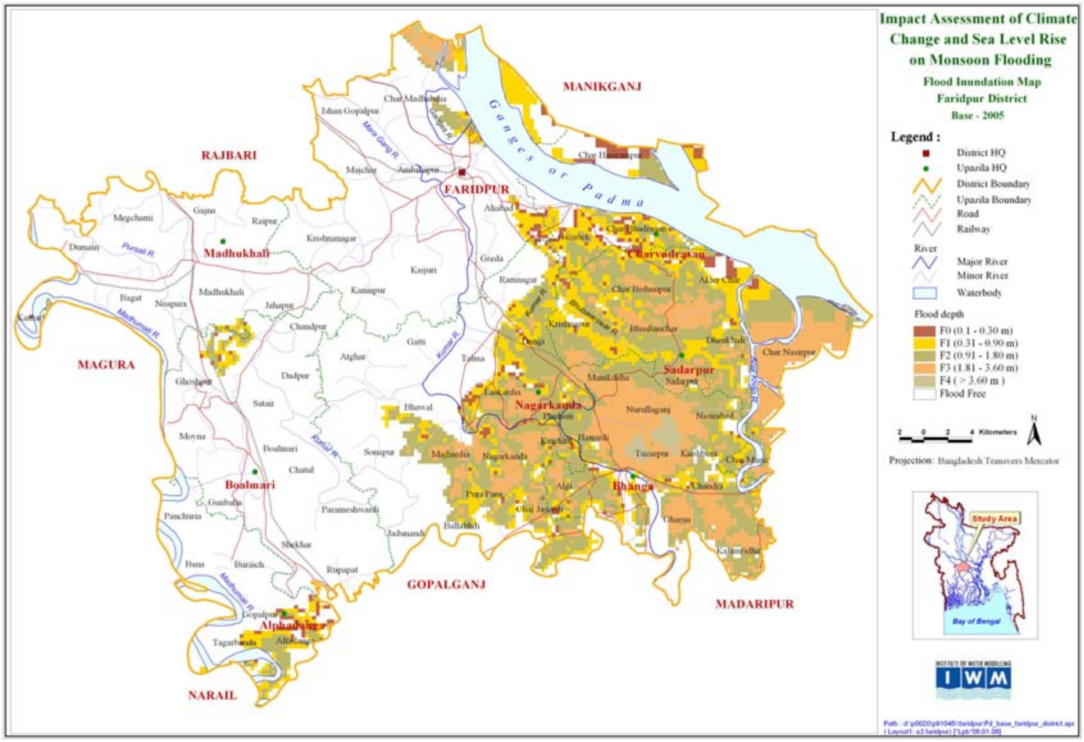

Figure B23: Inundated Area Base Condition, Faridpur District (Average Flood, Year 2005)

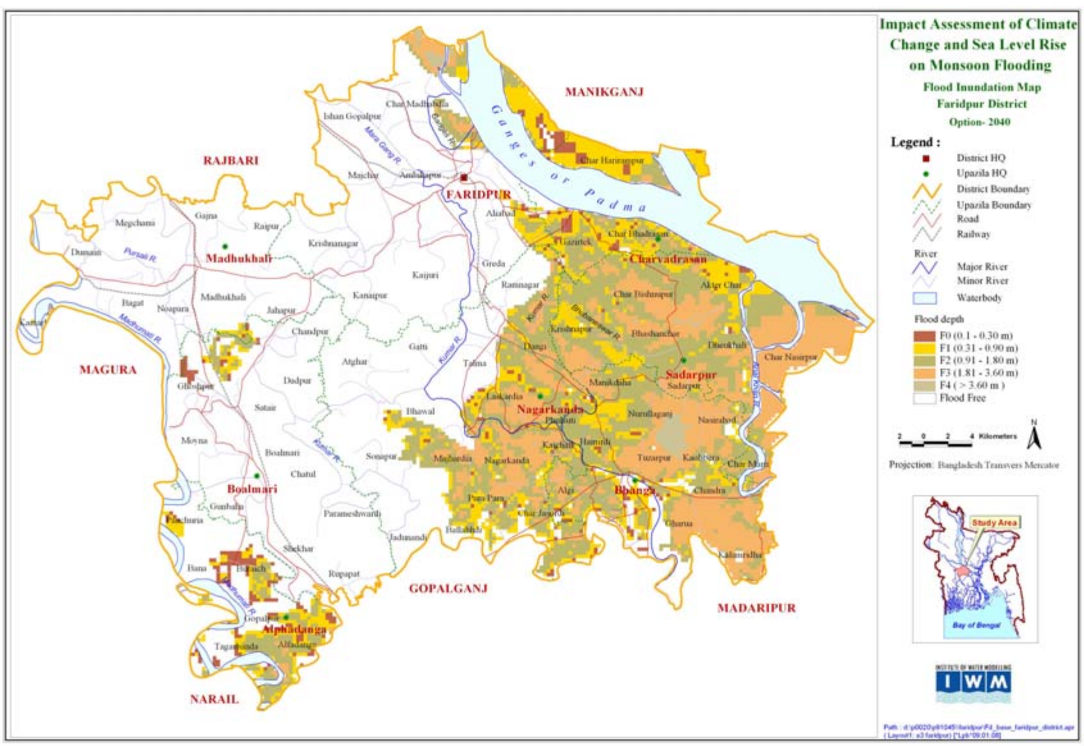

Figure B24: Impact on Inundated Area due to Climate Change Condition, Faridpur District (2040)

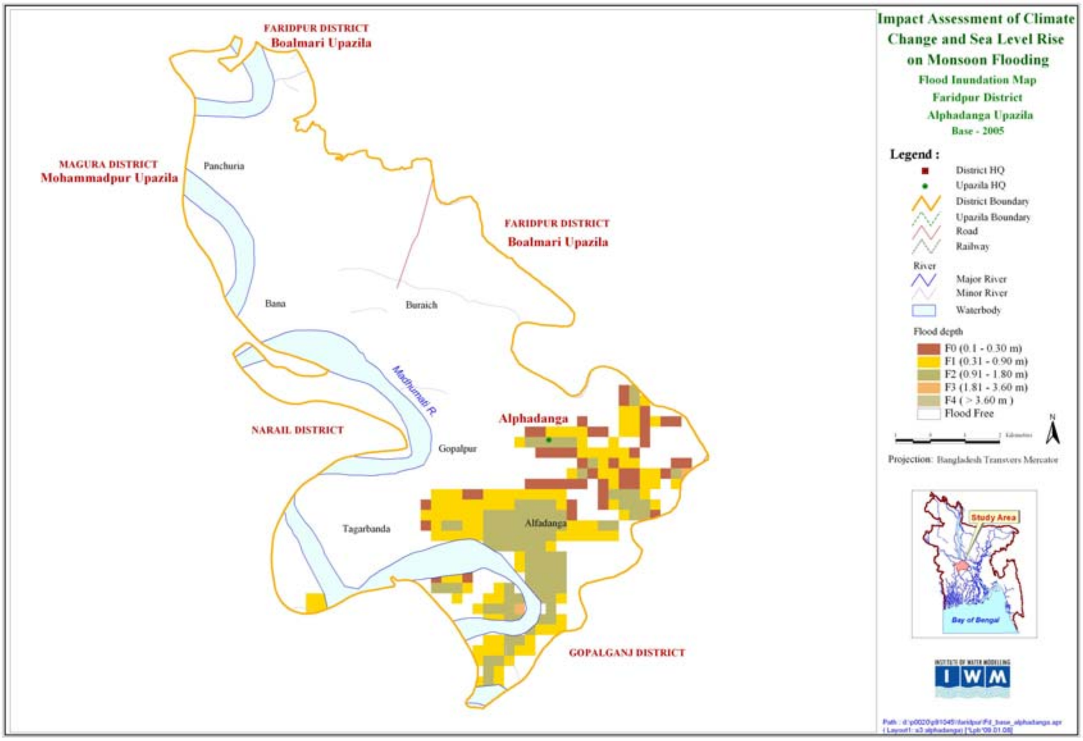

Figure B25: Inundated Area Base Condition, Alphadanga, Faridpur (Average Flood, Year 2005)

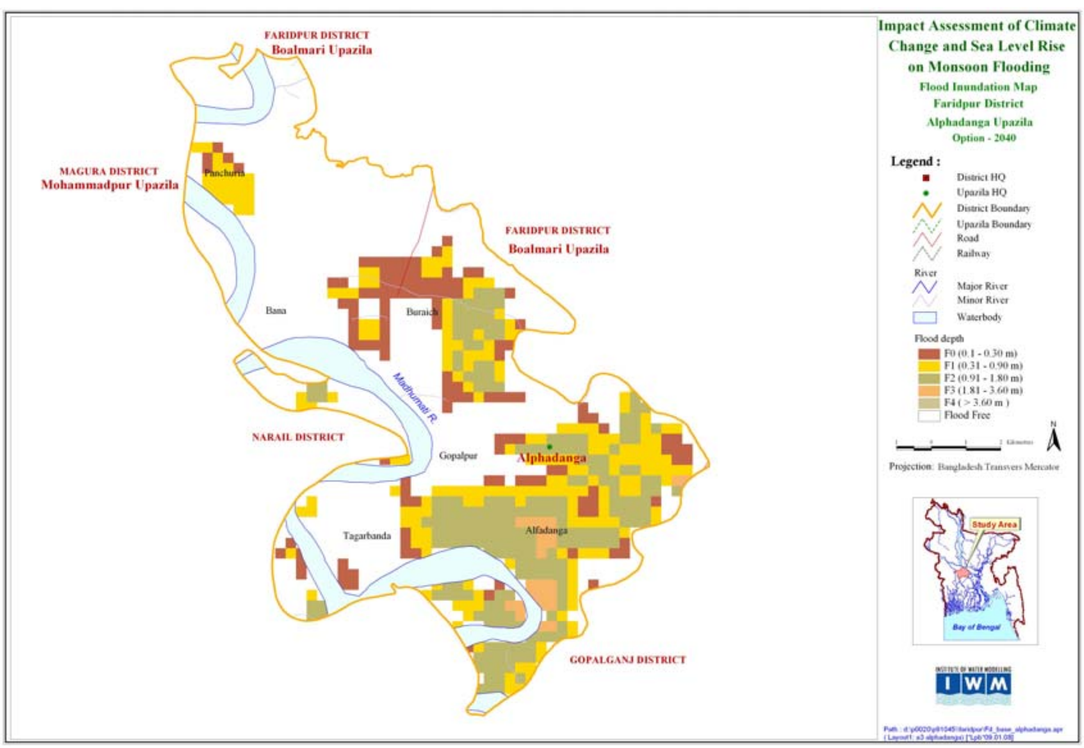

Figure B26: Impact on Inundated Area due to Climate Change Condition, Alphadanga, Faridpur (2040)

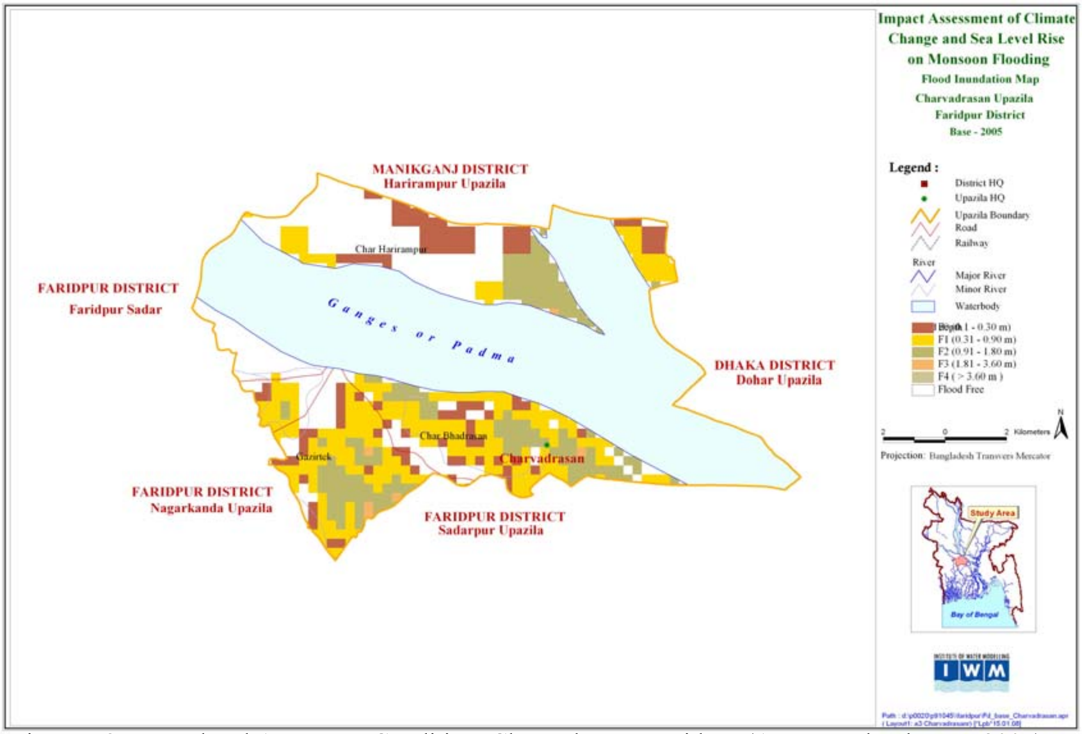

Figure B27: Inundated Area Base Condition, Charvadrasan, Faridpur (Average Flood, Year 2005)

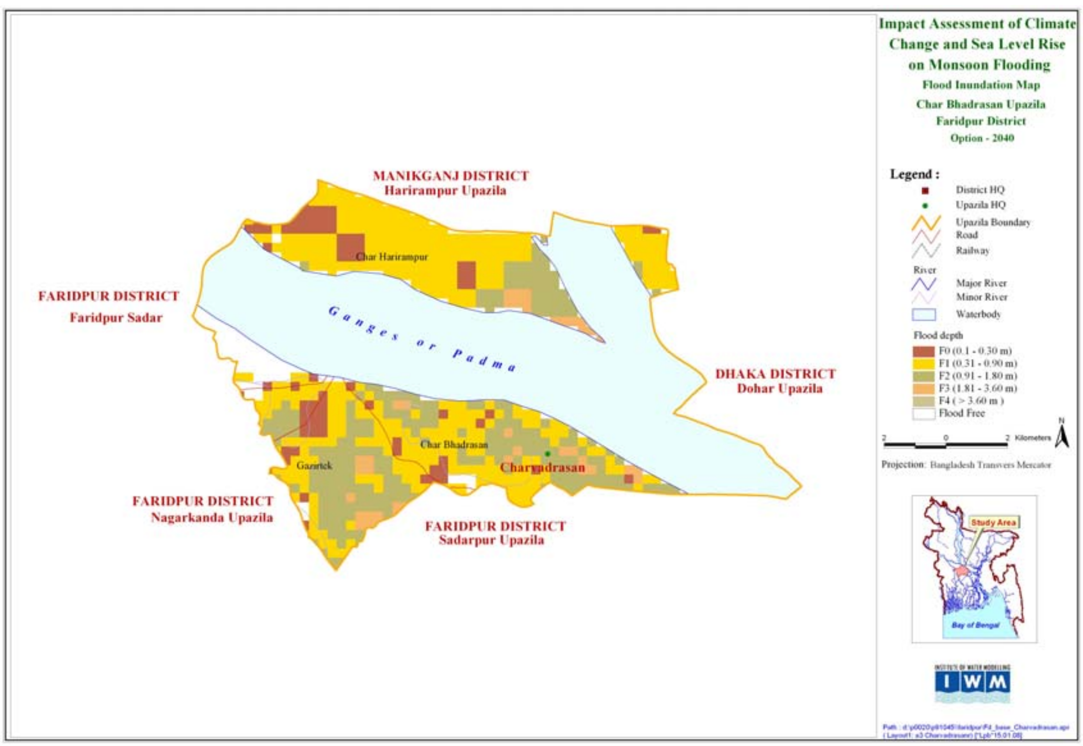

Figure B28: Impact on Inundated Area due to Climate Change Condition, Charvadrasan, Faridpur (2040)

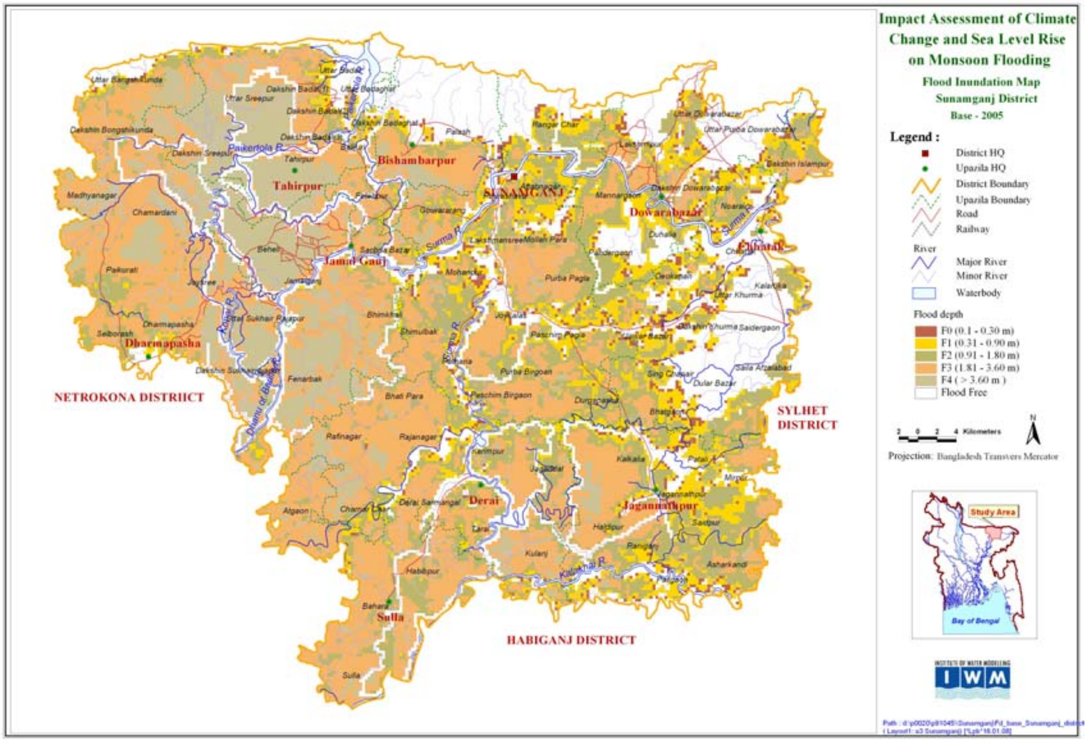

Figure B29: Inundated Area Base Condition, Sunamganj District (Average Flood, Year 2005)

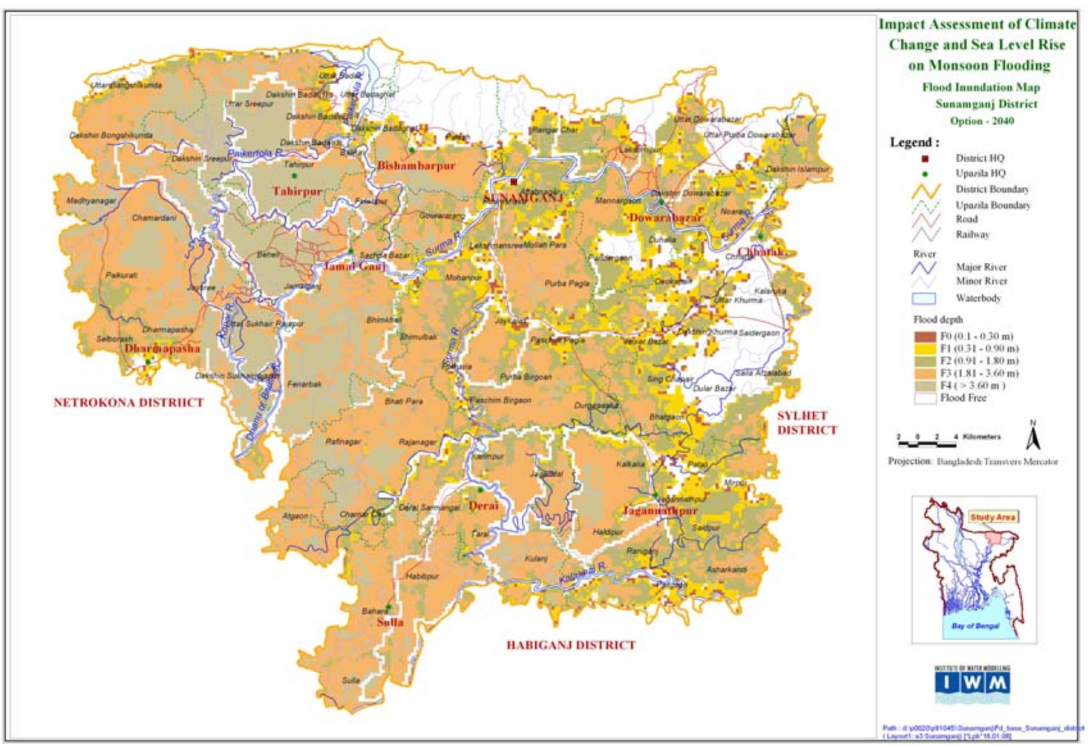

Figure B30: Impact on Inundated Area due to Climate Change Condition, Sunamganj District (2040)

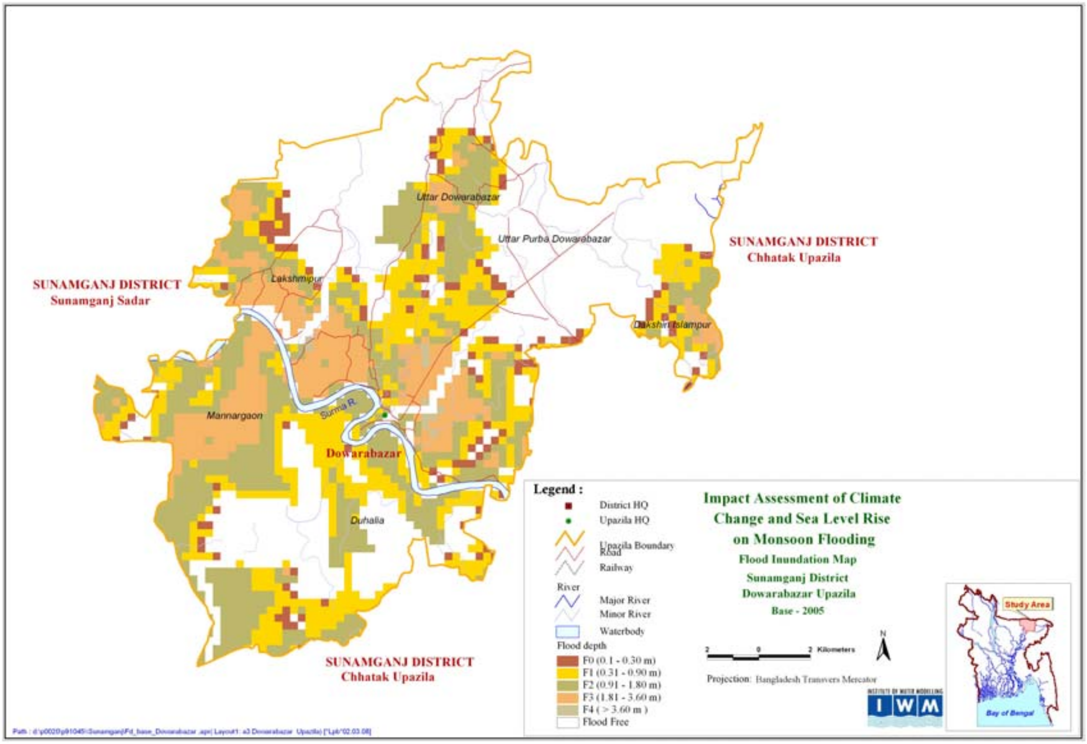

Figure B31: Inundated Area Base Condition, Dowarabazar, Sunamganj (Average Flood, Year 2005)

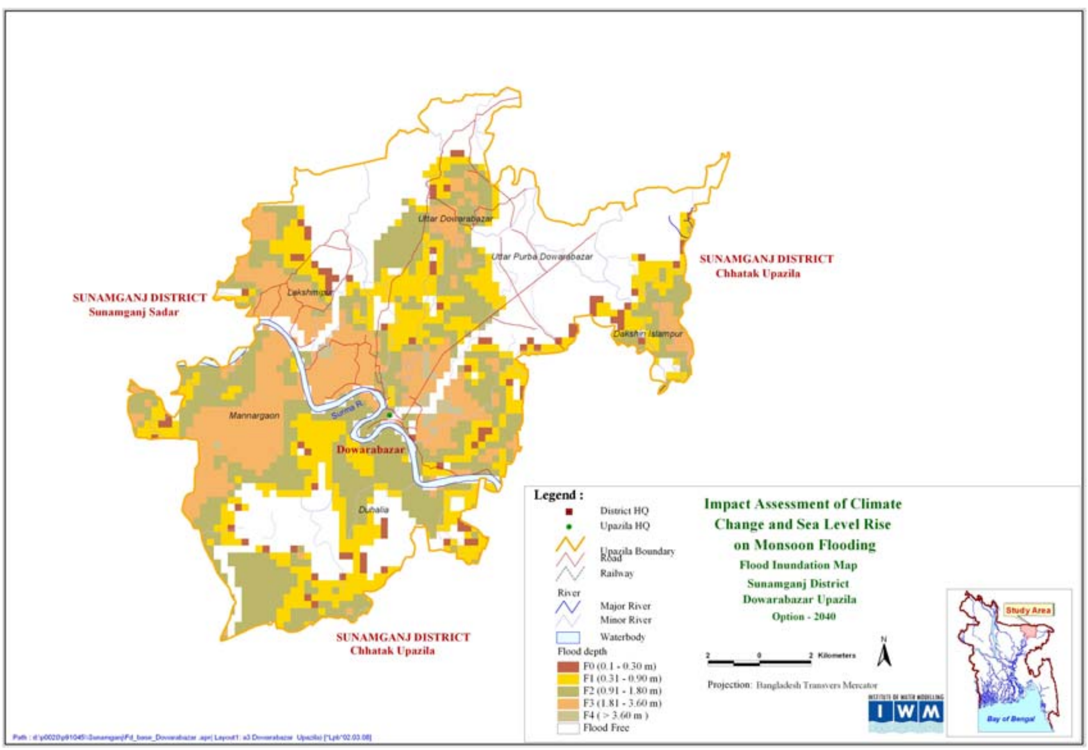

Figure B32: Impact on Inundated Area due to Climate Change Condition, Dowarabazar, Sunamganj (2040)

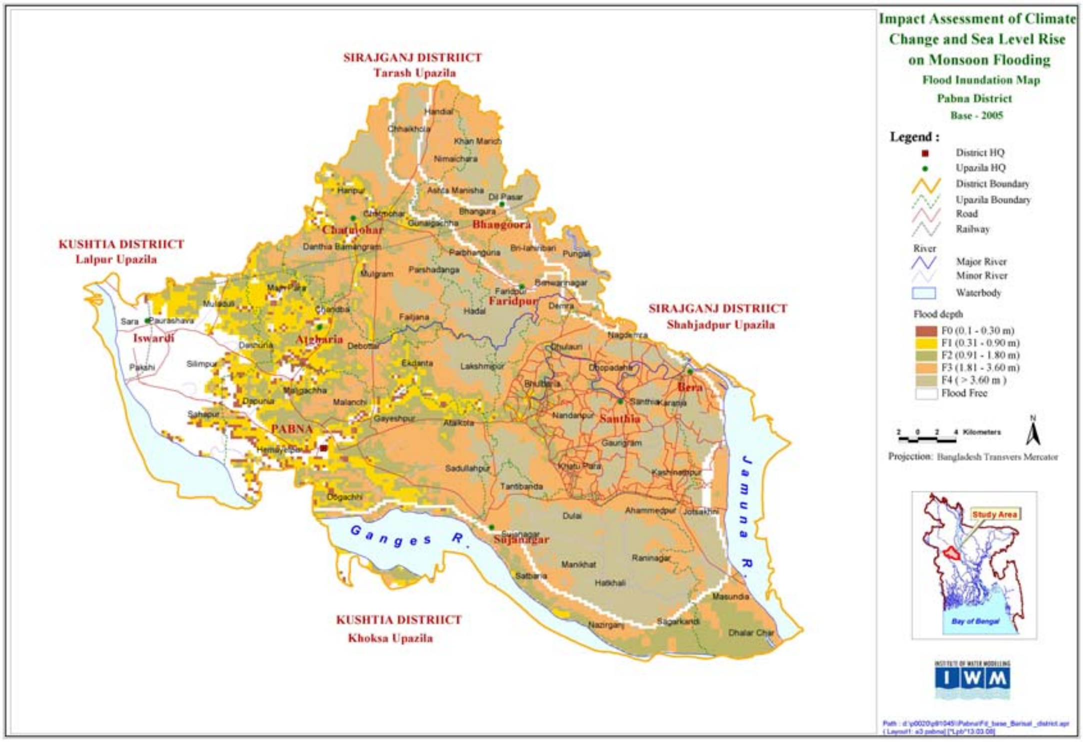

Figure B33: Inundated Area Base Condition, Pabna District (Moderate Flood, Year 2004)

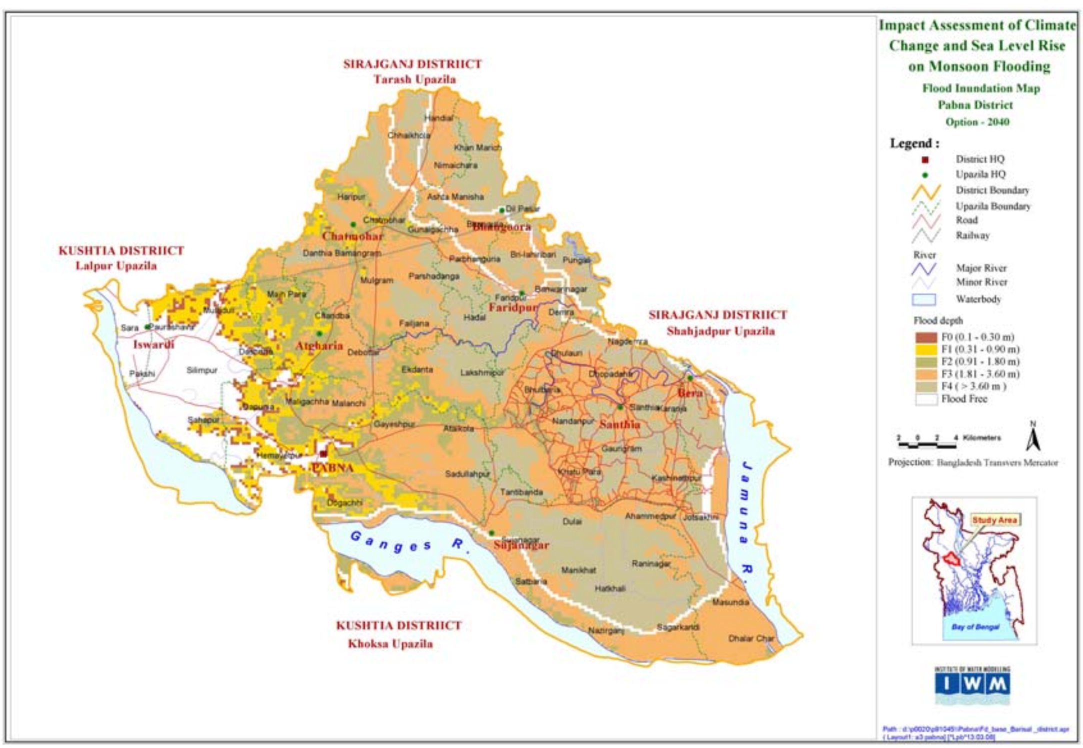

Figure B34: Impact on Inundated Area due to Climate Change Condition, Pabna (2040)

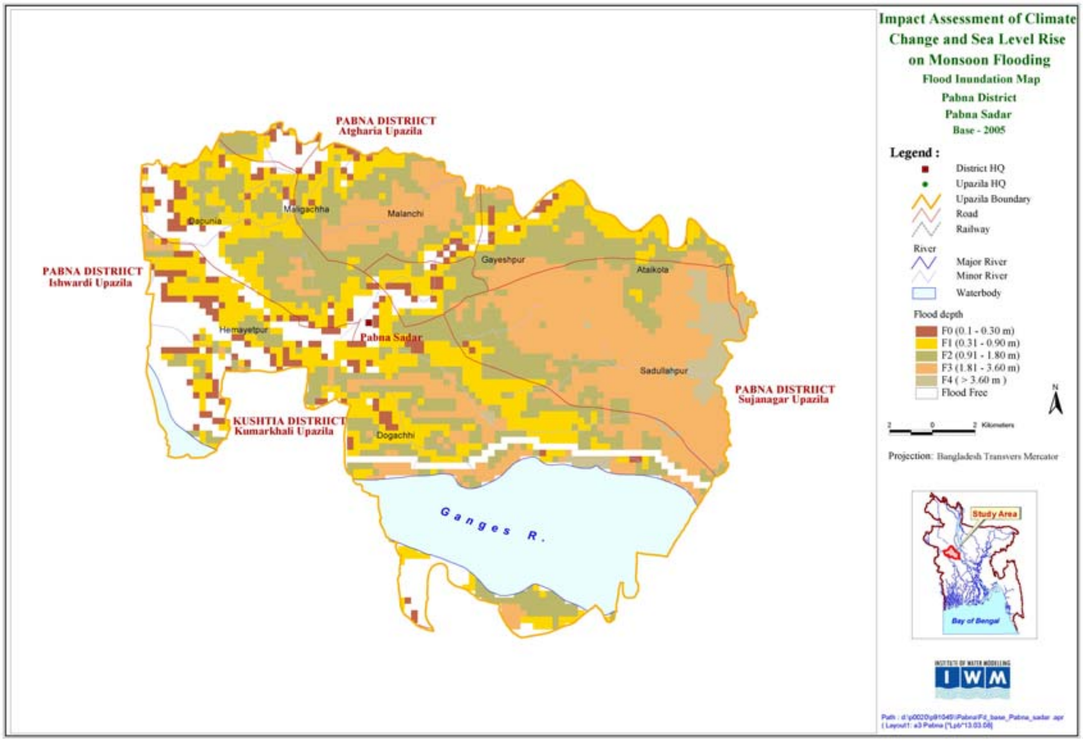

Figure B35: Inundated Area Base Condition, Pabna Sadar in Pabna (Moderate Flood, Year 2004)

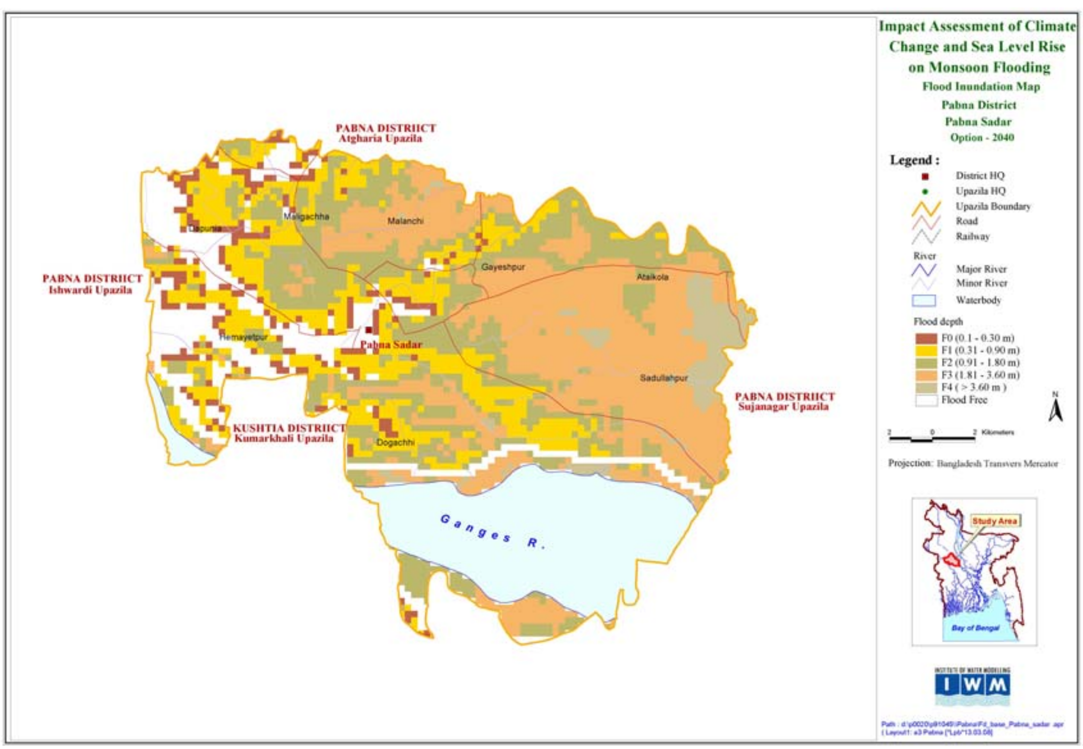

Figure B36: Impact on Inundated Area due to Climate Change Condition, Pabna Sadar in Pabna (2040)

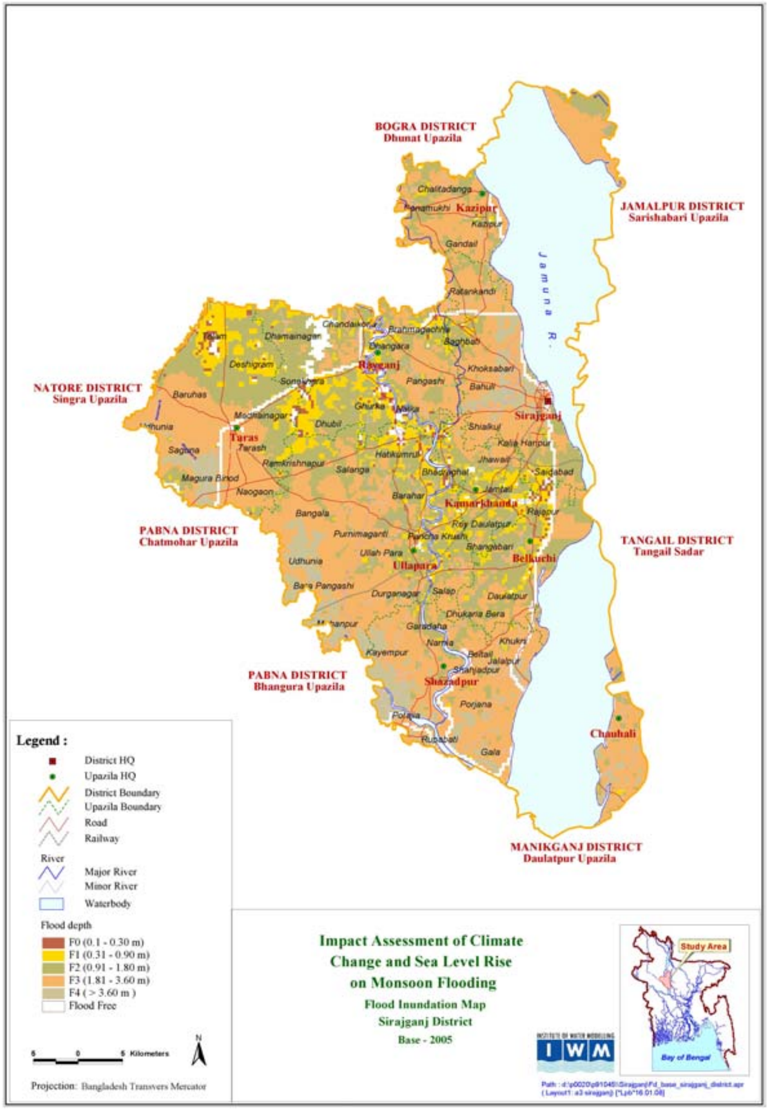

Figure B37: Inundated Area Base Condition, Sirajgang District (Moderate Flood Year, 2004)

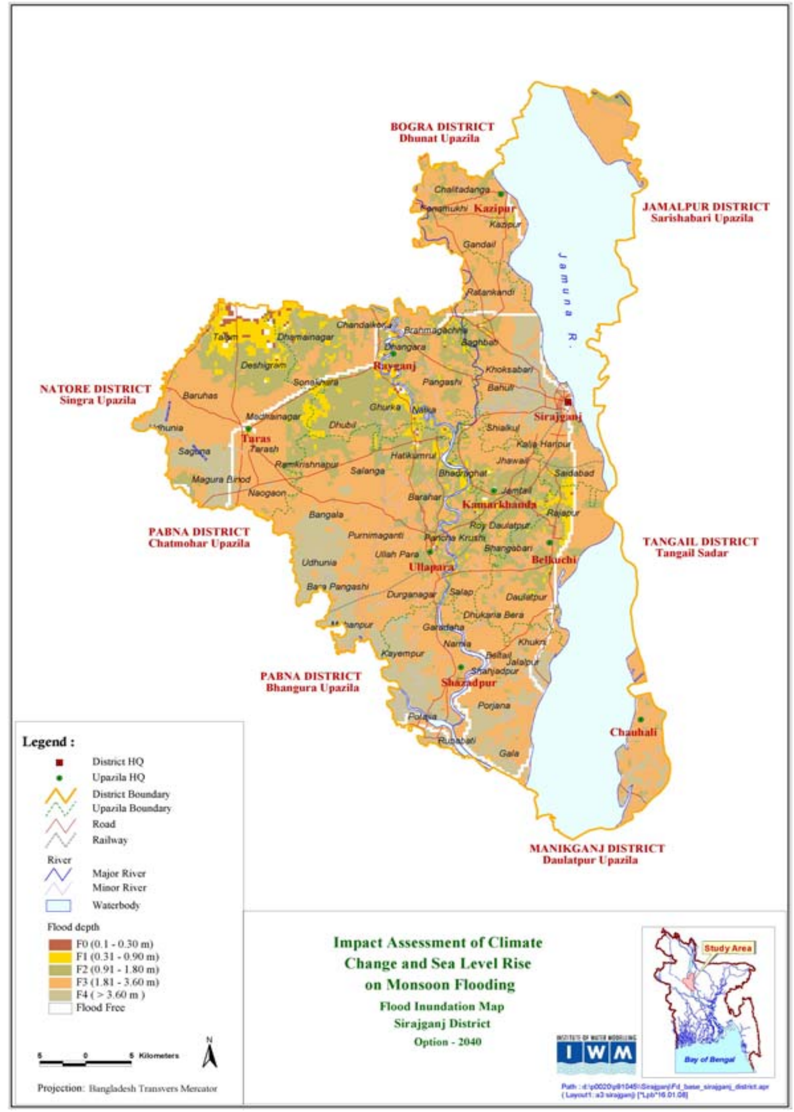

Figure B38: Impact on Inundated Area due Climate Change Condition, Sirajgang District (2040)

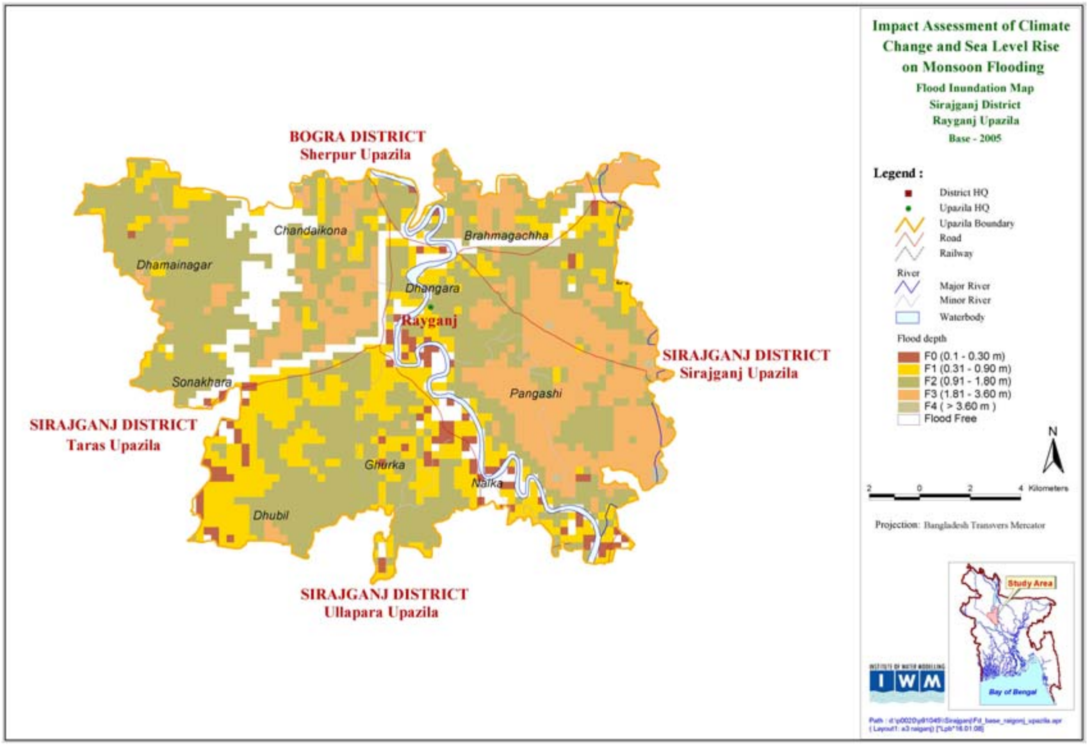

Figure B39: Inundated Area Base Condition, Raygang, Sirajgang (Moderate Flood Year, 2004)

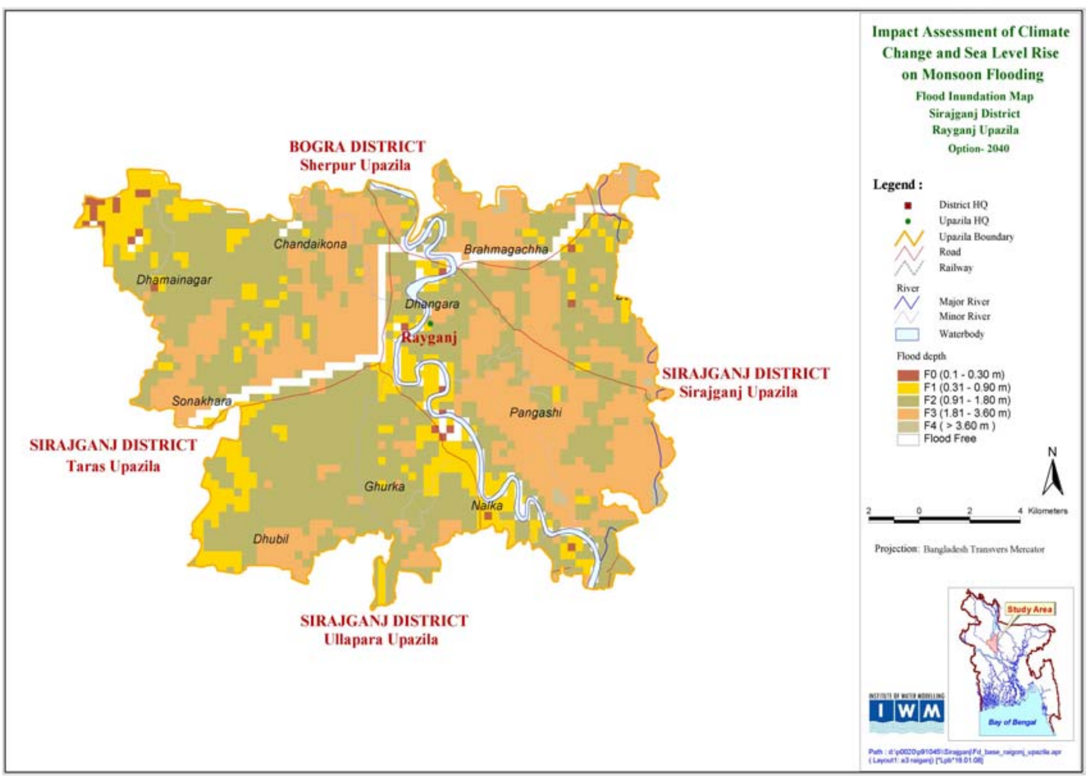

Figure B40: Impact on Inundated Area due Climate Change Condition, Raygang, Sirajgang (2040)

Appendix-C

Monthly change of land type due to climate change

Table C1: Change of land type over the monsoon due to climate change in Barisal District

Month	Year	Land Type (km^2)				
		F0	F1	F2	F3	F4
July	2005	141.21	1026.36	665.91	74.97	0
	2040	73.17	750.42	1067.04	118.89	0
August	2005	121.23	995.31	718.74	80.19	0
	2040	67.23	685.89	1138.86	115.02	0
September	2005	181.35	1086.57	505.17	69.21	0
	2040	96.12	913.32	875.52	87.48	0
October	2005	306	967.23	280.62	40.41	0
	2040	196.38	1128.33	441.9	62.64	0

Table C2: Change of land type over the monsoon due to climate change in Faridpur District

Month	Year	Land Type (km^2)				
		F0	F1	F2	F3	F4
July	2005	32.85	162	268.11	125.46	2.07
	2040	40.32	159.48	290.16	215.37	16.2
August	2005	25.11	141.84	289.17	163.71	5.58
	2040	29.61	152.28	290.16	237.15	18.45
September	2005	30.51	144.9	283.05	162.45	5.58
	2040	32.04	152.55	291.15	234.54	18.18
October	2005	31.86	112.32	153.99	52.11	0
	2040	38.7	154.89	205.2	68.58	0.09

Table C3: Change of land type over the monsoon due to climate change in Gaibandha District

Month	Year	Land Type (km^2)				
		F0	F1	F2	F3	F4
July	2005	73.8	407.16	484.29	105.3	0.36
	2040	73.53	331.74	566.91	222.66	0.9
August	2005	82.89	310.68	287.91	72	0.45
	2040	82.26	358.65	381.78	134.46	0.54
September	2005	51.93	220.41	140.22	15.66	0
	2040	54.36	247.23	250.92	65.07	0.45
October	2005	58.14	300.33	401.67	383.85	21.15
	2040	55.62	257.49	299.7	500.94	116.01

Table C4: Change of land type over the monsoon due to climate change in Pabna District

Month	Year	Land Type (km^2)				
		F0	F1	F2	F3	F4
July	2005	65.16	263.07	437.94	541.62	125.73
	2040	57.42	240.57	461.52	682.11	245.88
August	2005	64.08	207.9	479.34	535.68	119.34
	2040	40.32	176.85	390.78	702.99	232.2
September	2005	52.02	218.79	472.77	523.44	112.05
	2040	43.29	183.6	407.43	684.54	213.93
October	2005	33.48	108.54	161.91	179.91	8.82
	2040	56.79	154.8	226.89	265.86	26.64

Table C5: Change of land type over the monsoon due to climate change in Satkhira District

Month	Year	Land Type (km^2)				
		F0	F1	F2	F3	F4
July	2005	39.42	122.94	551.52	1658.52	0
	2040	26.91	128.79	241.65	2022.21	0.18
August	2005	37.98	130.32	419.58	1790.82	0.09
	2040	25.47	133.38	238.95	2019.87	0.54
September	2005	40.77	115.83	482.13	1741.68	0
	2040	33.39	123.39	217.17	2054.88	0.81
October	2005	33.57	134.91	747.9	1427.49	0
	2040	38.7	133.92	318.96	1906.92	0

Table C6: Change of land type over the monsoon due to climate change in Sirajganj District

Month	Year	Land Type (km^2)				
		F0	F1	F2	F3	F4
July	2005	56.52	404.73	698.94	415.71	11.61
	2040	34.56	239.49	691.47	741.87	33.93
August	2005	111.87	467.46	476.28	297.45	10.44
	2040	57.33	389.79	664.47	489.96	26.91
September	2005	120.33	461.97	475.56	270.99	8.19
	2040	73.35	422.46	648.45	435.51	21.87
October	2005	69.12	383.22	530.91	210.87	2.79
	2040	49.23	303.3	667.98	433.53	6.66

Table C7: Change of land type over the monsoon due to climate change in Sunamganj District

Month	Year	Land Type (km^2)				
		F0	F1	F2	F3	F4
July	2005	97.56	381.6	704.88	1180.98	472.95
	2040	72.27	338.4	672.93	1268.55	590.31
August	2005	116.1	423.54	715.14	1118.52	370.89
	2040	86.13	373.95	697.95	1234.17	486.72
September	2005	124.47	431.82	717.57	1051.38	334.35
	2040	102.24	392.58	679.59	1189.71	463.14
October	2005	137.88	465.21	694.62	685.98	136.53
	2040	129.6	443.79	715.77	752.76	184.14

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